PATTERNS OF SEDIMENTATION OF THE LOWER VINDHYAN SEQUENCE IN THE BHADESAR-NIMBAHERA AREA, RAJASTHAN

ABSTRACT

THESIS SUBMITTED FOR THE DEGREE OF

Doctor of Philosophy

IN

GEOLOGY

By

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DEPARTMENT OF GEOLOGY
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A B S T R A C T

The Lower Vindhyan (Middle Proterozoic) rock of the Bhadesar - Nimbahera area have been studied in respect of lithofacies, petrography and paleocurrent analysis with a view to interpret their provenance and depositional environment. This investigation is the first of its kind to have been attempted in the western part of the main Vindhyan basin and as such, provides important insight into the overall problems of Lower Vindhyan sedimentation.

Field work and geological mapping has confirmed the broad stratigraphic sequence established by earlier workers for southeastern Rajasthan of which the present area is a part. The approximately 1171m thick "Lower" Vindhyan sequence in the study area is conformable and is divisible into the following lithostratigraphic sub-divisions in the ascending order: Satola group (comprising Khairmalia Andesite, Khardeola Sandstone and Bhagwanpura Limestone Formations); Sand group (Sawa Sandstone and Palri shale Formations); Lasrawan group (Kalmia Sandstone and Binota Shale Formations) and Khorip group (Khori-Malan Sandstone, Jiran Sandstone, Bari Shale, Nimbahera Limestone and Suket Shale Formations).

The sandstones are immature to mature both texturally and compositionally. Most samples are medium to fine grained and

moderately to well sorted. The stratigraphic sections show an upward increase or decrease in grain size. However, in many sections vertical variations in grain size do not follow any definite trend. Similary the bulk of the sandstone are coarse to fine skewed and show positive (+) to negative (-) Skewness which perhaps suggests nearshore environment. By and large the sandstones are platykurtic to very leptokurtic. Log probability plots of grain size data suggest deposition mainly by surface creep and saltation. The detrital grains are mostly subrounded.

Mineralogically, Quartz is the dominant mineral and comprises 79.28% of the rock by volume. Feldspars are almost absent in the Khori-Malan and Jiran Sandstone but are present to the extent of about 3.25% and 8.72% in the Khardeola and Sawa Sandstone respectively. Heavy minerals are characterised by the predominance of subrounded to rounded grains of zircon and tourmaline. Fragments of Chert, quartzite, quartz schist and silt together make up 1 to 2% by volume. The sandstones are cemented by Silica, Iron Oxide and Clay. Cementing material is about 15% of the rock by volume. Petrographically four types of sandstones are recognised namely Quartzarenite, subarkose, sublitharenite and Arkose. In all the sandstone is 50% quartzarenite, 25% subarkose, 21% sublitharenite and remaining 4% arkose. Among the four sandstone formations, Jiran Sandstone is mineralogically mature followed by

Khardeola, Khori-Malan Sandstone which show slightly less maturity. The Sawa Sandstone is mineralogically least mature. The sandstone is derived from a stable craton and partly from recycled orogen. However, a marked variation towards mineralogical immaturity is seen in the sandstone of Sawa Formation which might have been mainly derived from recycled Orogen Provenance.

The limestone is predominantly micritic and dolomitic in composition and characterised by stromatolite, ripple marks, intraformational breccia and fenestrae or bird's eye structures. The major petrographic constituents are intraclast, sparry calcite cement, micrite and dolomite. Four microfacies were recognised namely micrite, silty micrite, intramicrite and dolomitized micrite.

The paleocurrent study, based primarily on the 1310 readings of cross-bedding foreset dip azimuth reveals that the direction of sediment transport is mostly poly direction i.e. southeast, northeast and west or north west through out deposition of the lower Vindhyan rocks. The paleogeographic setting of the basin suggests that the SE (seaward) and NW (landward) dispersals brought by reversing ebb tidal/foreshore and flood tidal/backshore currents. However, NE dispersal perhaps represents sediment transport by longshore currents. An integrated study of paleoflow pattern and mineralogy of the rocks suggests that in all probability the older Pre-Aravallis

(Bhilwara supergroup), Berach granite and Bhadesar quartzite out cropping adjacent to the study area in the north, west and south directions and constitute the provenance.

Lower Vindhyan sedimentation commenced with synsedimentational volcanic activity on an even basement of the pre-Aravalli metasediments or Berach granite with a unconformity as indicated by Khairmalia andesite. This was followed by deposition of the Khardeola Sandstone and stromatolitic Bhagwanpura Limestone. The occurrence of large scale cross-beds, coarsening upward sequence and polymodal paleocurrent distribution in Khardeola sandstone indicate shoreface to foreshore environment with occasional influence of flood tidal and/or Backshore currents. The stromatolite and intraformational breccia in the Bhagwanpura Limestone indicate a shallow fluctuating marine condition and deposition in a protected low energy subtidal lagoon to tidal flat environment. The occurrence of arkose and conglomerate in Sawa Sandstone, coarsening upward, bimodal paleocurrent direction and its overlapping relationship indicate unstability and some changes in the provenance and oblique bar-rip channel nearshore environment of deposition with the intermittent tidal influence. As the seaward migration of the shore lines continued the nearshore sediments were covered by Back-Barrier (subtidal lagoon) to high intertidal deposits represented by Palri shale, Kalmia Sandstone and Binota Shales. As a result of unstable fluctuating basin condition, transgression take place and Barrier intertidal to surf zone with flood dominated tidal sediment deposits as represent by Khori-Malan Sandstone. The Jiran Sandstone is represented by foreshore-barrier beach sediments with effect of ebb dominated tidal currents. As the seaward migration of the shoreline still continued, the foreshore-beach deposits were gradually replaced by intertidal zone which are now represented by Bari shale. The very extensiveness of the submerged shelves prevented wave action and the shallowness promoted super-saturation of the sea water with Calcium Carbonate and this combination of physical and chemical conditions resulted in the active precipitation of carbonate mud forming the massive Nimbahera Limestone. An increase in the rate of clastic sedimentation, perhaps in response to tectonism in the source area, cut off carbonate sedimentation and initiated the deposition of Suket Shale on the newly formed intertidal and supratidal mud flats.

The deposition of repetitive sequence of sandstone, shale and limestone during Lower Vindhyan sedimentation may be possible due to recurrent incursions and regression of sea water in a pulsating manner through out the Lower Vindhyan sedimentation associated with consequent frequent shifts in the strandline or shoreline of deposition being caused by upheaval in the provenance and penecontemporaneous adjustments in the basin under epierogenic condition.

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DEDICATED
with
Love and Affection
to
My Parents & wife

B.D. BHARDWAJ
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25th January, 1995

I certify that the work presented in this thesis has been carried out and completed by ***Mr. Naresh Kumar Mathur*** *under my supervision at the Department of Geology, Aligarh Muslim University, Aligarh.*

This work is an original contribution to our understanding of lithostratigraphy, lithofacies, texture, petrography, paleoflow, depositional environments and paleogeography of the Lower Vindhyan rocks of Bhadesar - Nimbahera area of southeastern Rajasthan. The research work presented herein has not been published any where in part or in full.

I recommend that ***Mr. Naresh Kumar Mathur*** *be allowed to submit the thesis for the award of the degree of* ***DOCTOR OF PHILOSOPHY IN GEOLOGY*** *at the Aligarh Muslim University, Aligarh.*

(B.D. BHARDWAJ)

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INTRODUCTION

PURPOSE OF STUDY

Recent researches have no doubt enhanced our understanding of Vindhyan sedimentation in different parts of the country, particularly in respect of paleodrainage, depositional environments and paleogeographic setting. There are nevertheless many critical areas about which sedimentological information is as yet vitally lacking for a proper evaluation of sedimentation model of Vindhyan rocks. The choice of the area for the present investigation was influenced solely by the above consideration.

The geology of the Vindhyan Supergroup in southeastern Rajasthan has been worked out fairly by early workers and deal locally with such aspects as texture and petrography of sediments. The last 25 years have witnessed a tremendous advancement in the concepts of sedimentology and in approach to sedimentological investigations. Presently, the emphasis is laid down on appropriate quantitative methods. The present investigation is an attempt to make an integrated field, petrographic and paleocurrent study in a small area of the western part of the basin, with a view to determine the dispersal pattern, provenance, depositional environments and paleogeography of the Lower Vindhyan rocks.

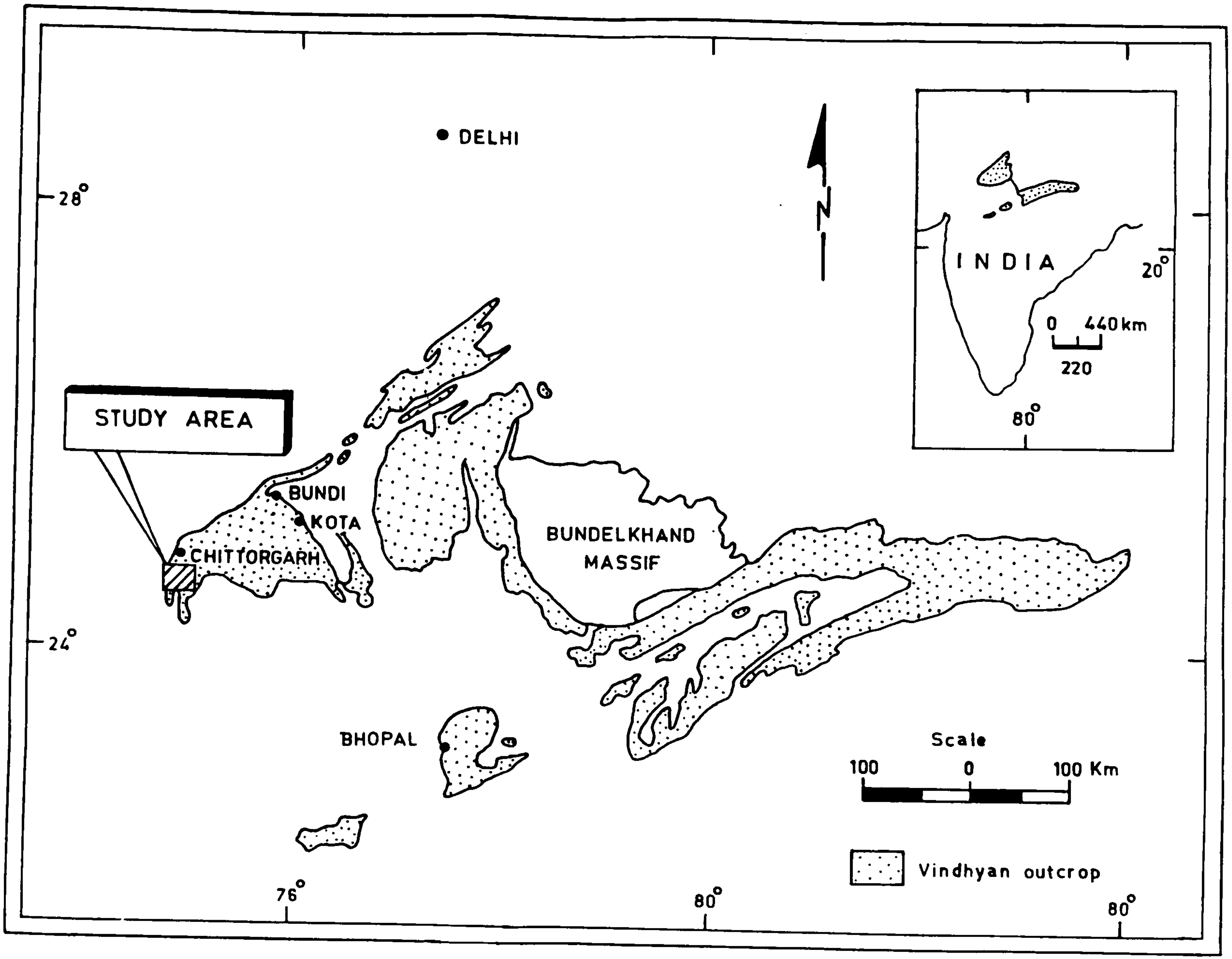

Fig.1 Index map of the Vindhyan Basin showing location of the study area. Inset shows position of the Vindhyan Basin in India.

LOCATION OF THE STUDY AREA

The present study was carried out in the western part of the Vindhyan basin (Fig. 1). The study area, limited by east longitudes 74° 30' and 74° 45' and north latitudes $24^{\circ}30'$ and $24^{\circ}45'$, covers about 675 sq. km. and is located in the Chittorgarh district of southeastern Rajasthan and Mandasur district of west Madhya Pradesh.

SCOPE OF STUDY

The present investigation deals with four lower most sedimentary groups of Lower Vindhyan Supergroup namely Satola, Sand, Lasrawan and Khorip. In field study each outcrop was examined in detail for various sedimentary facies and primary features and appropriate measurements recorded and data collected including rock samples for petrographic study.

Vertical arrangements of different lithofacies is deducted, foreset dip azimuth of cross-bedding and other directional parameters so recorded were statistically analysed to deduce paleoflow and paleoslope across the basin of deposition. Thin sections of rock samples were carefully examined for determing texture and mineral composition of framework and cement or matrix. Heavy minerals were also identified in thin section study to supplement petrographic description.

It is believed that an integrated study of facies analysis and paleoflow combined with the results of petrography and relevant published work should help to decipher the sedimentation history of Lower Vindhyan sedimentation in the given area.

ACKNOWLEDGEMENT

The author is indebted to Prof. B.D. Bhardwaj for suggesting the problem and supervising the entire course of the work. Many thanks are extended to Prof. Iqbaluddin, Chairman, Department of Geology, Aligarh Muslim University, Aligarh, for providing various facilities for research work. The author express his gratitude to Prof. S.M. Casshyap and Dr. M. Razia, Reader of the same department for numerous discussions. Valuable help rendered by my colleagues, Dr. Adal Singh and Dr. A.H.M. Ahmad, Lecturer, Deptt. of Geology, at various stages of this study requires special mention. The author is thankful to his colleagues Dr. M. Aslam, Dr. M. Arora, Mr. Abdullah Khan, Mr. B.K. Srivastava and Mr. Zakir Hussain for their help in numerous ways. Lastly, the author expresses his thanks to Mr. U.C. Sharma and Mr. Mujtaba Ahmed, Aligarh for typing the thesis and in the preparation of photographs.

NKMathur

(NARESH KUMAR MATHUR)

C H A P T E R - 1

G E O L O G I C   S E T T I N G

Previous Work

Williams was the first geologist who studied the Vindhyan rocks of "Keymore" range in the West of the Son river in the early part of 1848. Oldham (1856) studied Vindhyan rocks of Central India and proposed the name "Vindhyan" for all the formations seen in the scarps of the Vindhyan range and classified them into three subgroup, "Kymore", "Rewah" and "Bundair" in ascending order. Medlicott (1859), in his report on the Vindhyan rocks of Bundelkhand agreed with the classification given by Oldham. However, he observed a group of rocks comprising limestone, shale and Sandstone between the Vindhyan rocks and the crystalline basement and termed it "Semri series".

The earliest comprehensive account of the Vindhyan system of North western and Central parts of India, was
/by brought out /Mallet in 1869. He retained the above mentioned three fold classification of Oldham, but the rocks older than Kymore Subgroup were named as Lower Vindhyans. Coulson (1927) mapped the erstwhile State of Bundi in Rajasthan and provided the detailed account of geology and structure of the area. Auden (1933) made a detailed study of the stratigraphy and sedimentation of the Vindhyan rocks of the Son-Valley (Mirzapur district) and divided the system into four series namely Semeri, Kaimur, Rewa and Bhander, but discarded the use of the terms "Lower" and "Upper" Vindhyans. He was the first to study the lithology of the rock types and their origin. He also worked out the physiographical conditions prevailed

during the Vindhyan times.

The area under study was studied in detail for the first time by Heron (1936). He mapped the area on 1 inch to 4 miles and discussed the lithology and structural features of the Vindhyan rocks.

During the last four decades, a great deal of work has been carried out on various aspects of Vindhyan rocks such as stratigraphy and Primary Sedimentary structures (Banerjee and Sinha, 1981; Barman and Verma, 1980; Mathur, 1955, 1965, 1981; Mathur et. al. 1962; Misra, 1961; Misra and Awasthi, 1961, 1962; Mohan, 1968; Prasad, 1975, 1976, 1981, 1984; Prasad and Verma, 1991; Sahni, 1961; Sarkar, 1981; Sastry and Moitra, 1984, Soni et. al. 1987; Valdiya, 1982), Palaeogeography and Sedimentation (Ahmad, 1962, 1981; Akhtar, 1976, 1978; Banerjee, 1964; Banerjee and Singh, 1981; Banerjee and Sengupta, 1963; Bhardwaj, 1973, 1977, 1978; Bhardwaj and Mathur, 1989; Chandra and Bhattacharya, 1982; Ghosh, 1981; Jafer et. al, 1966; Lakshmanan, 1981; Murti, 1981; Prasad, 1984; Rao et. al, 1981; Singh, 1978, 1980; Srivastava, 1977; Srivastava and Mehrotra, 1981 and Srivastava et. al, 1983).

However most of the above studies are connected with small areas and do not take into consideration the integrated aspect of Vindhyan Sedimentation.

The terms Upper and Lower Vindhyan proposed by Mallet (1869) have been retained only for reasons of long usuage and they have penetrated in the geological literature so much that it becomes difficult to avoid them.

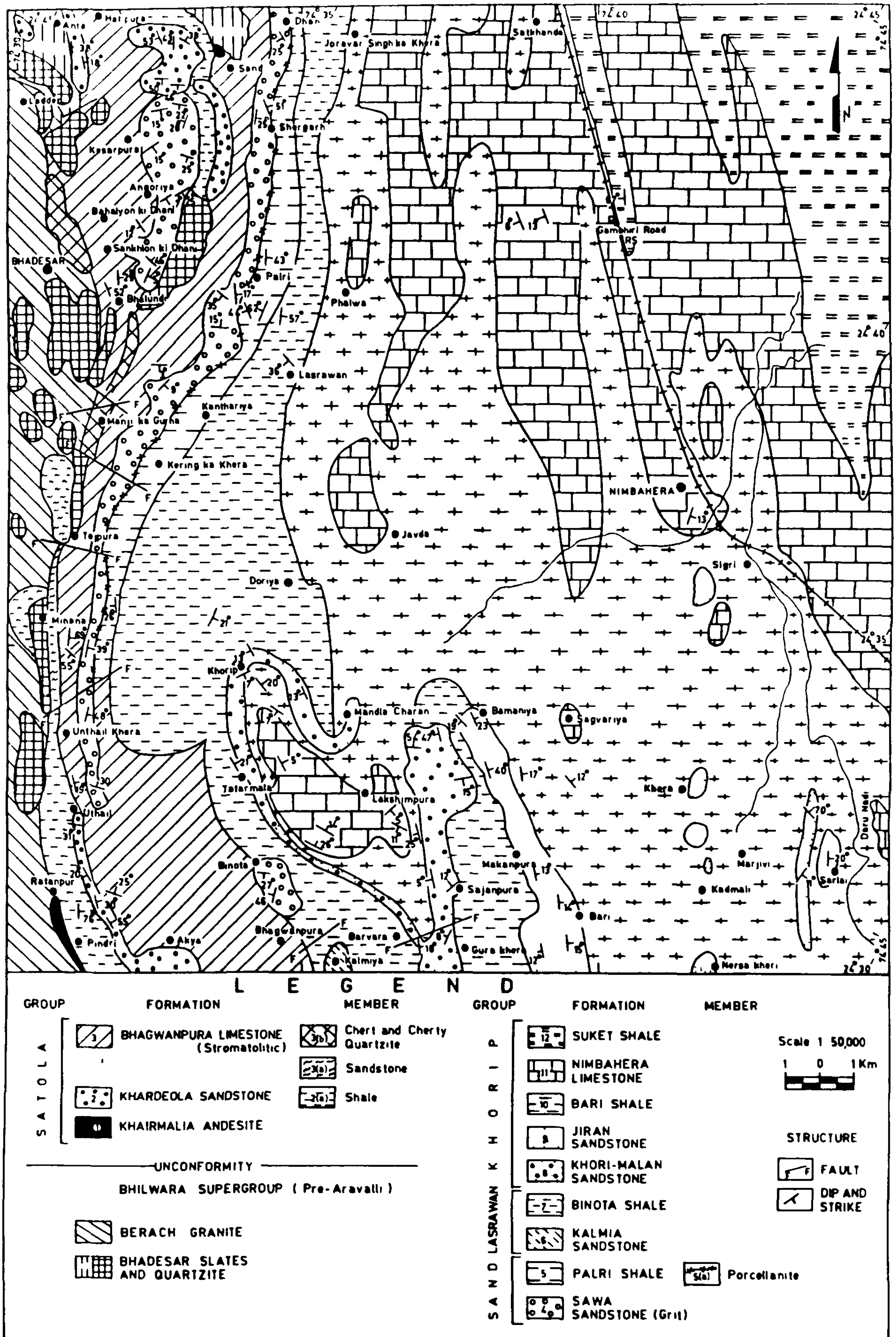

Fig 2 Geological map of Lower Vindhyan rocks of Bhadesar-Nimbahera area, Southeastern Rajasthan

Table - 1 Stratigraphic Succession of Lower Vindhyan sequence in the Bhadesar - Nimbahera area, Southeastern Rajasthan.

GROUPS	FORMATIONS	MEMBERS	THICKNESS (in meter)
KHORIP (382 m)	**Suket Shale**		**120**
	Nimbahera Limestone		**148**
	Bari Shale		**45**
	Jiran Sandstone		**24**
	Khori-Malan Sandstone		**45**
LASRAWAN (175 m)	**Binota Shale**		**160**
	Kalmia Sandstone		**15**
SAND (140 m)	**Palri Shale**		**60**
		Porcellanite	**20**
	Sawa Sandstone		**60**
SATOLA (474 m)	**Bhagwanpura Limestone**		**300**
	(Stromatolitic)	Coarse Sandstone	**60**
	Khardeola Sandstone		**44**
		Shale	**60**
	Khairmalia Andesite		**10**
	UNCONFORMITY		
Pre-Aravalli (Archaean - II, > 2550 m.y.)	**Bhilwara Supergroup**	**Berach Granite** (Late tectonic emplacement)	
	Bhadesar Formation	Shale, Slate & Phyllite with Quartzite and Dolomite.	

Gross lithology and field characters

The Lower Vindhyan rocks of the study are provided excellent opportunity to study the sediments in aspects of lithology, primary sedimentary structure, palaeocurrents and environment of deposition.

The unmetamorphosed and undeformed Middle Proterozoic sediments forming the Vindhyan Supergroup occur in a large arcuate basin along the northern edge of the Indian shield. The Bundelkhand massif, located north of the central sector of the Vindhyan Basin divides it into a western and an eastern part (Fig. 1). In western part, the Vindhyan Supergroup is divisible into seven groups : the Satola, Sand, Lasrawan, Khorip, Kaimur, Rewa and Bhander (Prasad, 1984).

The area between Bhadesar and Nimbahera has been studied and remapped on a scale of 1:50,000 (Fig. 2). The sequence measuring 1,171m is divisible into four groups : the Satola, (474m), Sand (140m), Lasrawan (175m) and Khorip (382m) (Table-1, Fig. 2). The sandstone and the Archaean rocks forms the ridges having generally north-south strike where as shale and limestone forms the low grounds in the area.

Basement rocks

The basement rocks (Pre-Aravallis or Bhilwara Supergroup) composing Bhadesar Formation and Berach Granite are overlain by Vindhyan rocks with unconformity in the study area. The Bhadesar Formation is consist of shale, slate, phyllite, dolomitic limestone and quartzite. This formation is well exposed as long ridges from north to south in the western part of the area. The Bhadesar Quartzite is white and pink, jointed and very fine grained.

The Berach Granite is well developed from north to south in western part of the area and lies below or directly in contact with the Bhadesar Quartzite, Bhagwanpura Limestone and Khardeola Sandstone. The Berach Granite has been dated by Crawford (1968) as 2585 m.y. old. Thus metasediments of the Bhilwara Supergroup are older than 2585 m.y. The Lower Vindhyan sequence rests unconformably on Bhilwara supergroup. At places the Bhilwara Supergroup is overlain unconformably by Khairmalia Andesite, Khardeola conglomerate or Bhagwanpura conglomerate.

Satola Group

The Satola group which forms the base of Lower Vindhyans in the study area has been named after a village and is divisible into three formations (Prasad, 1984) namely Khairmalia Andesite, Khardeola Sandstone and Bhagwanpura Limestone. The Khairmalia flow is synsedimentational with Khardeola sandstone which is overlain by Bhagwanpura Limestone and show gradational contact at some places. However, in the northern part Bhagwanpura Limestone overlies directly on the Pre-Aravalli metasediments with marked unconformity. The Pre-Aravalli Formations show high dip and various grades of metamorphism. The Satola group is mainly arenaceous and calcareous and about 474m thick.

KHAIRMALIA ANDESITE

The Khairmalia Andesite is the oldest formation of the Satola group and comprising flows of andesitic composition interbedded with sandstone (Khardeola Formation) and has been named after the locality Khairmalia. Heron (1936) referred this formation as "Khairmalia amygdaloid" and included in the Aravalli system. This formation is poorly exposed except in Unthail, Pindri to Ratanpur and south east of Kannauj where it occurs in scattered patches. The rock is fine grained and dark purple, pink, greenish and greenish brown in colour. The Khairmalia Andesite rests unconformably on the Berach Granite at Pindri and on the Bhadesar Phyllite and slates in Sand area. The formation passes into Khardeola Sandstone upwards. The flow and sandstone are interbedded and as such the Khairmalia Andesite mark the beginning of the Vindhyan sedimentation in Rajasthan.

KHARDEOLA SANDSTONE

The Khardeola Formation rests conformably over the underlying Khairmalia Andesite. Howerver it rests unconformably on the Berach Granite in south west of the area and over the Bhadesar phyllite and slate in north west of the area. The best exposures occur at Unthail, west of Ladder and from Sand to east of Angoria (Fig. 2). The Khardeola Formation is mainly composed of sandstone, but at places contain shale intercalation in base of it.

The Khairmalia flows are synsedimentational with the Khardeola sandstone but where the Khairmalia flows is absent,

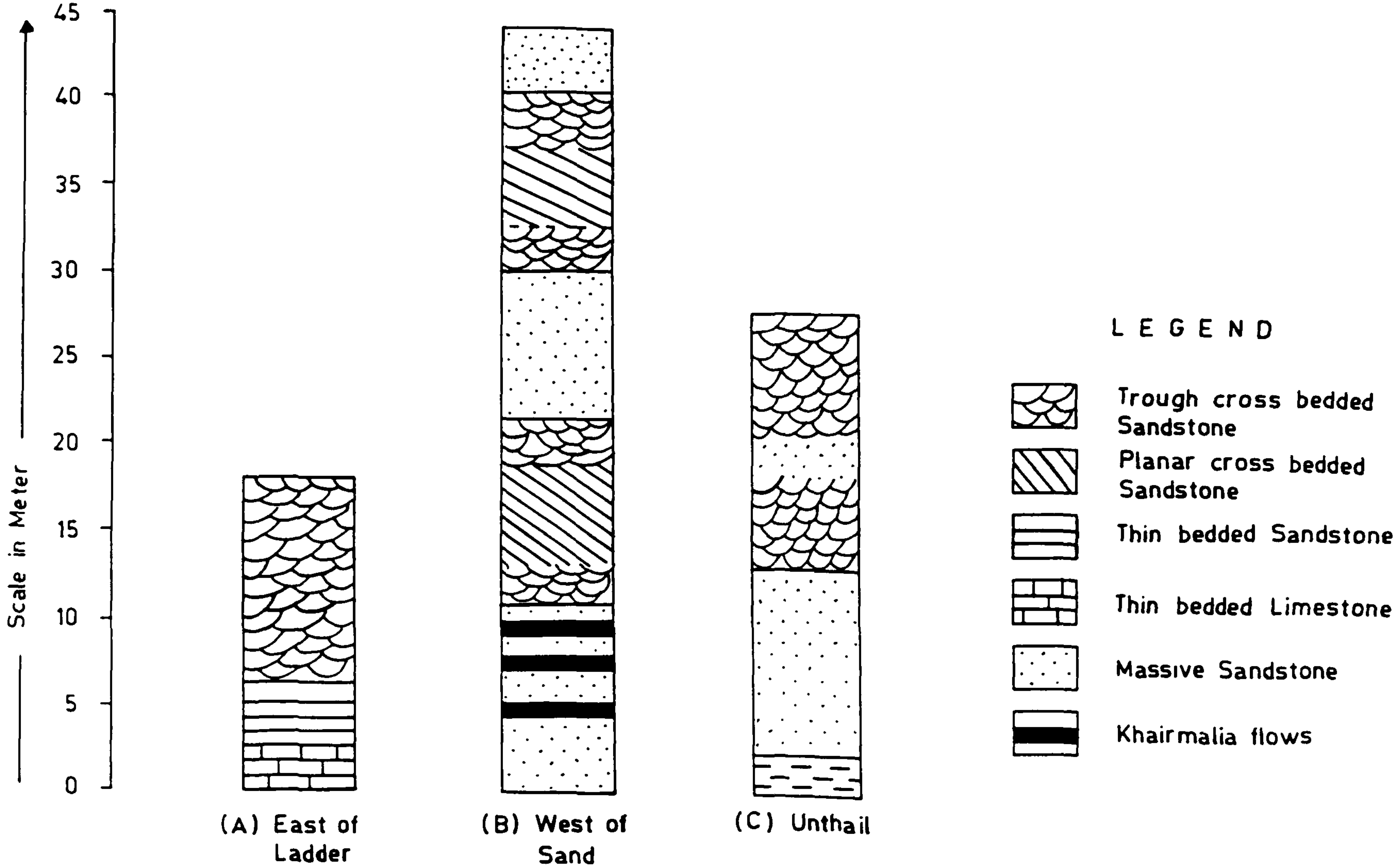

Fig. 3 Stratigraphic sections of Khardeola Sandstone Formation measured at east of Ladder (A), west of Sand (B) and Unthail (C).

this formation unconformably overlies the Pre-Aravallis. Prasad (1984) estimated the thickness of the formation to be of the order of about 60 meter near Khairmalia (out side study area) but the measurement of three stratigraphic sections in the area (Fig. 3) has revealed that its thickness is not same everywhere and varies from 18 metre in east of Ladder to 44 metre in west of Sand.

The stratigraphic sections were measured at three localities to evaluate the lithology, primary sedimentary structure and their distribution in space and time (Fig. 3).

In north west of the area, the Khardeola Sandstone is well exposed as long ridge at Ladder area (Fig. 3 A). Here the sandstone is 18m thick and overlies the Bhadesar shale with gradational contact and dipping in easterly direction at an angle ranging from 18^{o} to 38^{o}. The base about 2m thick sequence of thin bedded, very fine grained, yellowish pink limestone overlies the Bhadesar shale (Pre-Aravallis). The passage from shale to limestone is about 1 meter. This limestone gradually passes into thin bedded, massive fine grained, bluish pink to purple calcareous sandstone. Thickness of sandstone is about 3.5m and the individual bed thickness ranges from 4 to 7 cm. Higher up, in the sequence thin bedded sandstone gradually passes into about 12m thick, cross bedded sandstone. The sandstone is fine to medium grained, thick bedded, brownish white, pink to yellowish white in colour. The cross bed is mostly large scale trough type and occur in coset. The thickness of the cross beds gradually decreases from base to top ranging from 4 cm to 50 cm.

The maximum thickness of Khardeola Sandstone occur in the west of Sand where a section about 44 m thick is exposed. The basal 10.5 m of the exposed section consists of massive, fractured, thick bedded, pinkish white to blackish grey coloured sandstone with anticlinal high dip in the range of 35^{o} to 55^{o}. This massive sandstone is devoid of all internal structure and interbedded with Khairmalia flows (Plate - 1 Fig. 1) as give the evidence that Khardeola Sandstone is synsedimentational with Kharimalia flows. The individual bed is ranging in thickness from 50 cm to 1.5 m. Higher up in the sequence, the sandstone is cross bedded, medium grained, pinkish white in colour and having thickness of an order of 10 m. The cross bedding is large scale, mostly planar type but at places the trough type is also common. Overlying it is 9 m thick pinkish white massive sandstone followed by 10m thick cross bedded, greyish to blackish pink coloured, fine to medium grained sandstone with gradational contact. The cross bedded sandstone is overlain by 4m thick massive sandstone. The massive sandstone is fine to medium grained, pinkish grey to pale brown in colour. The thickness of individual bed range between 50cm to 2.5m.

The Khardeola Sandstone is well exposed in several disconnected outcrops and overlain unconformably by Bhagwanpura Limestone between Unthail and Akya (Fig. 3 C). At Unthail about 28m thick sequence of Khardeola Sandstone was measured. In the basal part occurs the thin bedded red shale of 2m thick. Higher up in section about 11m thick, massive, thick bedded, pinkish white, fine grained sandstone is

PLATE 1

Fig.1

Fig.2

P L A T E - 1

Fig. 1 Photograph of Khardeola Sandstone inter bedded with Khairmalia flow give evidence of synsedimentation; Khardeola Formation.

Fig. 2 Photograph of limestone showing nodular structures; Bhagwanpura Formation.

exposed with sharp contact. The massive sandstone is overlain by about 15m thick cross bedded sandstone. Middle part of this sandstone is massive in nature, fine grained, pinkish white to yellowish pink, pale brown in colour and show mostly of large scale trough type cross bedding. Each bed is range in thickness from 50cm to 2.5m and dipping towards easterly with high dip (25 to 55^{o}) but at place show westerly dip due to folding.

In general, the Khardeola Formation is composed of sandstone and shale. The basal beds of Khardeola sandstone are interbedded with the Khairmalia flows. The sandstone is thick to thin bedded, massive, fractured, cross bedded and show considerable variation in grain size from very fine to coarse grained. The sandstone is yellowish pink, pinkish white, reddish grey and grey in colour and show mostly easterly dip in the range of 18 to 55^{o} but at places it westerly due to folding. The individual beds are few centimeters to 2.5m thick. The shale is characteristically red and purple in colour and occur occasionally in the basal part of the formation.

BHAGWANPURA LIMESTONE

The Bhagwanpura Limestone overlies the Berach Granite or Bhadesar Quartzite with a distinct unconformity but in southern part from Unthail to Akya in the south of the area it overlies conformably on the Khardeola sandstone with gradational contact. From north to south in western part of study area the Bhagwanpura Limestone is well developed and very persistent. The Formation comprised of limestone, shale, sandstone, cherty quartzite and conglomerate. The later varies as intercalation.

Due to the general scarcity of recognisable stratification and its known irregularities of original deposition, of folding, it is impossible to estimate the exact thickness of the Bhagwanpura Limestone, but the aggregate thickness varies considerably. The maximum thickness according to Heron (1936) is about 300m (Fig. 5). The individual beds are 15cm to 50cm thick. The general dip of the limestone is to east or southeast in the range of 3 to 55^{o} but due to folding, faulting and unequal subsidence at some places show southwest or westerly dip.

The Bhagwanpura Limestone occurs in a wide band of black rocky country, generally uncultivated but in places show weathering with knobby, reticulated irregularly fractured surfaces, varying amounts of quartz veining and cherty impregnation. Good exposures are seen west of Hatipura, north east of Angoria, around Bahalyon Ki Dhani, east of Bhalundi, west of Palri, west of Shergarh and around Bhagwanpura.

The Bhagwanpura Limestone is impure, mainly dolomitic and siliceous. It is very fine grained, thin to thick bedded, hard and compact. Generally it is pale coloured, creamy or bright brownish-yellow and a thin bedded variety is almost white, but it grades in colour to brown-purple and even a deep crimson with increasing amounts of iron oxides. The Limestone is mostly massive and stromatolitic but at places also show ripple marks, intraformational breccia (conglomerate) (plate

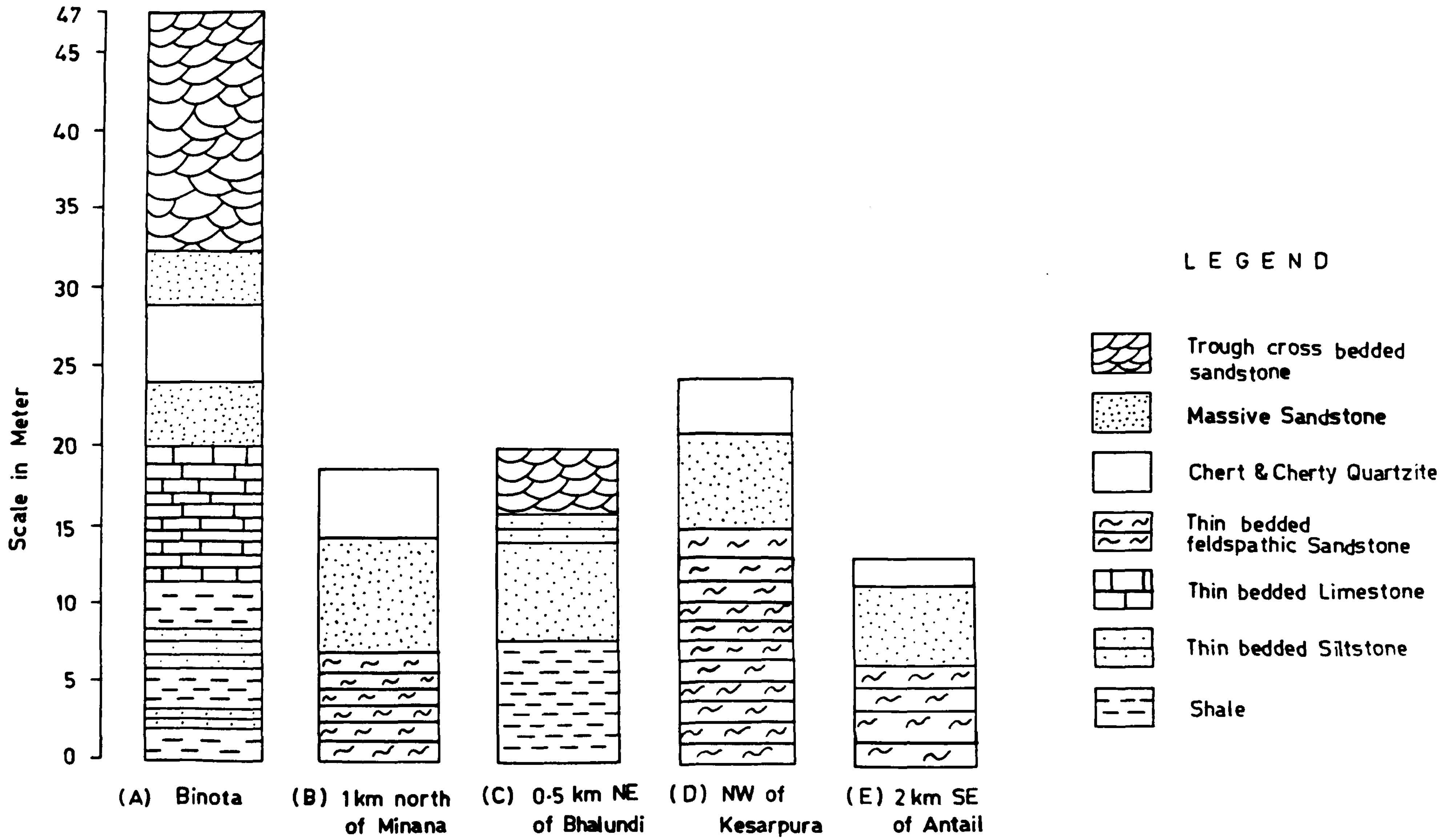

Fig. 4 Stratigraphic sections of Sandstone of Bhagwanpura Formation measured at Binota (A), 1km north of Minana (B), 0·5 km NE of Bhalundi (C), NW of Kesarpura (D), and 2 km SE of Antail (E).

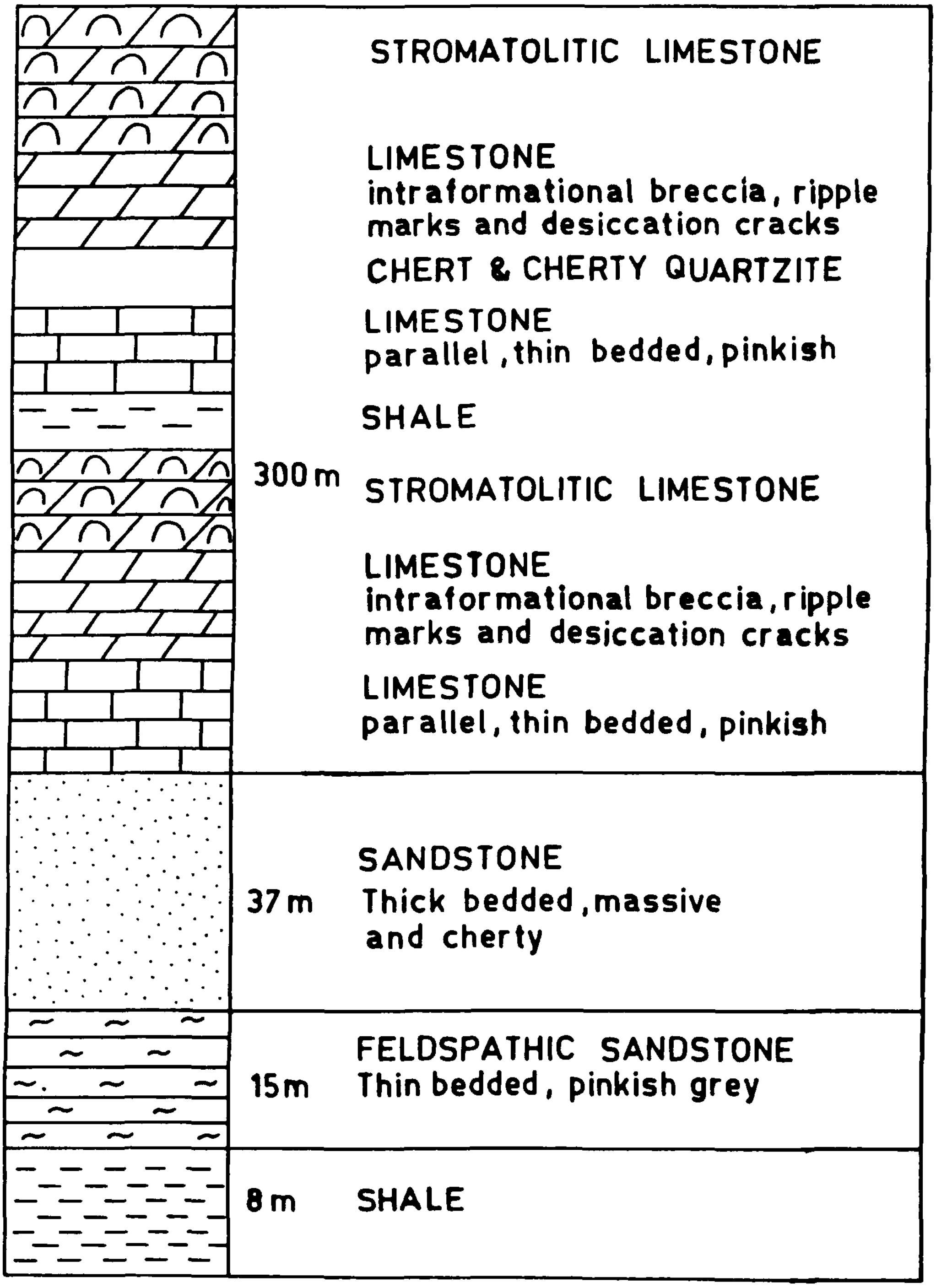

Fig. 5 Generalized sequence of Bhagwanpura Limestone Formation.

PLATE 2

Fig. 1

Fig. 2

P L A T E - 2

Fig. 1 Photograph of thin bedded shale showing intercalation of siltstone; Bhagwanpura Formation. Hammer (30 cm) for scale.

Fig. 2 Photograph of cherty quartzite; Bhagwanpura Formation. Hammer (30 cm) for scale.

17, Fig. 1), desiccation cracks and nodular structures.

In the study area, stromatolite is brownish-yellow to black in colour and show columns which grow upward by the addition of convex laminae. Good exposures of algal structures are seen around Bhalundi, north of Angoria, east of Bhagwanpura (Plate 17, Fig. 2) and near Unthail Khera. Prasad (1976, 1978, 1980), Raja Rao and Mahajan (1965), Barman and Verma (1980) and other worker have recognised several species of Colonella, Kussiella, Conophyton and Weedia assemblages of columnar stromatolites as described by Raaben (1969), Cloud and Semikhatov (1969). The noncolumnar types are laminated, broken ripple like structures (Plate 17, Fig. 1) and correspond to the LLH-C and LLH-S types of Logan et. al. (1964).

Thin nodular structure are also recorded at surfaces near Unthail Khera and Angoria (Plate 1, Fig. 2) in which the whole mass of the rock is composed of spheres approximately equal in size and touching each other, like pisolitic texture on a much larger scale. In the Unthail Khera the spheres are 9 or 10 inches in diameter and are composed of concentric layers. At Angoria the spheres are small, 1 to 2 inches in diameter and do not show concentric layers to the same extent. According to Heron (1936), they are organic in origin. Prasad (1984) say that they originated from blue green algae.

Bhagwanpura Sandstone is well exposed in the form of low lying hillocks at several places. The sandstone is thick bedded, massive, pink, grey and brownish in colour. They vary in thickness from 7m to 15m and show easterly dip in the range of 10 to 30^{o}. The sandstone are associated with or overlain by chert and cherty quartzite and underlain by thin bedded feldspathic sandstone which altered into clay beds. The chert and cherty quartzite occur as bouldery outcrops. Due to nonavailability of outcrops only five stratigraphic sections were measured at Binota, 1km north of Minana, north east of Bhalundi, north west of Kesarpura and 2km south east of Antail (Fig. 4A to 4E) to evaluate lithology and primary sedimentary structures and their distribution in space and time.

A 47m thick section of sandstone, shale and limestone rocks were measured at Binota (Fig. 4A). In the Binota ridge, 12m thick shale, exposed at the base, is thin bedded, reddish to yellowish green in colour and show intercalation of siltstone (Plate 2, Fig. 1). Higher up in the sequence, the shale in gradually passes into thin bedded, brownish coloured Bhagwanpura Limestone. Thickness of this limestone is about 8m. After that about 12m thick, fine grained sandstone is exposed. The sandstone is massive, cherty, pink, dark yellow to grey in colour and occur in bouldery outcrops. Due to faulting in area, the sandstone is brecciated with irregular joints and not show distinct bedding. This brecciated sandstone is intervened by hillocks of chert and cherty quartzite and shows the unconformity between the underlying Bhagwanpura Limestone and the overlying Sawa Sandstone. Higher up in sequence about 15m thick Sawa Sandstone of younger (Sand) group is form the top most outcrop of the hill. The Sawa Sandstone is medium grained, trough cross bedded and greyish white to pinkish white in colour and exposed up to second Bhagwanpura ridge. Each trough cross bed is range in thickness from 50cm to 1m.

About 1km north of Minana, Bhagwanpura Sandstone is well exposed in low hillocks (Fig. 4B). Here sandstone in basal part is thin bedded, massive, fine grained, feldspathic and pink in colour. But in upper part it becomes thick bedded, massive, medium grained and grey in colour. This sandstone is about 17m thick and overlain by massive, yellowish to dark tan, 4m thick chert and cherty quartzite. The chert and cherty quartzite occur as bouldery outcrops (Plate 2, Fig. 2). The thin bedded feldspathic sandstone is altered into clay beds. It is inferred that the formation of clay was due to the alteration of feldspathic sandstone present in the area. Clay occurs as bedded deposit and occasionally contain some fragments of unaltered feldspathic sandstone.

About 0.5km north east of Bhalundi, the Bhagwanpura Sandstone is also well exposed and show different lithology than discribed earlier (Fig. 4C). In the measured sequence, the basal part is consist of about 8m thick, brown to green coloured shale. Above this 12m thick sandstone is exposed. The sandstone in lower part is massive, pink to green in colour but in upper part it is greenish green, thick and trough cross bedded. The sandstone show shale partings in some places.

North west of Kesarpura and 2km south east of Antail, the Bhagwanpura Sandstone is again well exposed (Fig. 4D & E). The sandstone is about 5m thick, massive grey coloured, thick bedded and overlain and underlain by cherty quartzite and altered feldspathic sandstone respectively. In Kesarpura area, the feldspathic sandstone is about 15m thick. In the area, these feldspathic sandstone is crops out by private companies as clay. The clay is of inferior quality and is used in the manufacture of pozolona cement only.

The intraformational breccia or conglomerate occur occasionally in the formation, exposed near Bhagwanpura, 1.4km north east of Kesarpura, Manji Ka Gurha to Unthail Khera. The intraformational breccia is present locally in the limestone units. It consists of angular, subrounded and platy fragments of limestone. The intraformational breccia or conglomerate is a rudaceeous deposit formed by penecontemporaneous fragmentation and redeposition of the carbonate stratum. The breccia is thin to thick bedded, individual beds being 0.5m to 1m thick. The total thickness of intraformational breccia varies from 10 to 30m at place to place.

From Manji Ka Gurha to Unthail Khera the intraformational breccia is well exposed in Nallas and show cherty quartzitic bands which are mostly parallel to the strike.

The intraformational breccia near Kesarpura is poorly exposed, but examination of well section indicates that it may be more than 30m thick. It contains subrounded grains of quartzite, quartz and feldspar in mainly clayey matrix.

In the formation, shale occur as lenses within the limestone at a few places. They are interbedded with and grade into limestone, being generally calcareous. At some places shales are silty and show microcurrent bedding. Shale is white, red, crimson, green, yellow to purple and generally show colour banding resulting in variegated nature.

Chery and cherty quartzite are found as thin impersistent lenticular bands through out the limestone horizon. They occur in bouldery outcrops forming low lying hillocks at several places (Plate 2, Fig. 2). It is a grey, dark yellowish to dark tan in colour. They vary from 3 to 15m in thickness and can be traced for a long distance. The cherty quartzite is fine grained, massive and consists of well rounded grains of quartz cemented by secondary silica.

In general, the Bhagwanpura Limestone Formation as a whole is consist mainly limestone with intercalation of shale, chert and cherty quartzite in the upper part and in small thickness of conglomerate, sandstone,shale in the lower part (Fig. 5). Conglomerate locally occur in basal part of the formation but in several places sandstone also lies in the lower part of the formation with clay band.

Sand Group

It comprises of Sawa Sandstone with conglomerate band and Palri Shale Formation associated with porcellanites. The group name is taken after the village Sand where it is well developed. The group contain arenaceous and argillaceous sediments and is about 140m thick.

SAWA FORMATION

The Sawa Sandstone is composed of coarse to fine grained sediments with occasional development of conglomerate beds. The sandstone forms long ridges running from Dhani in north to Unthail, 1km north of Kesarpura to Sankholin Ki Dhani and

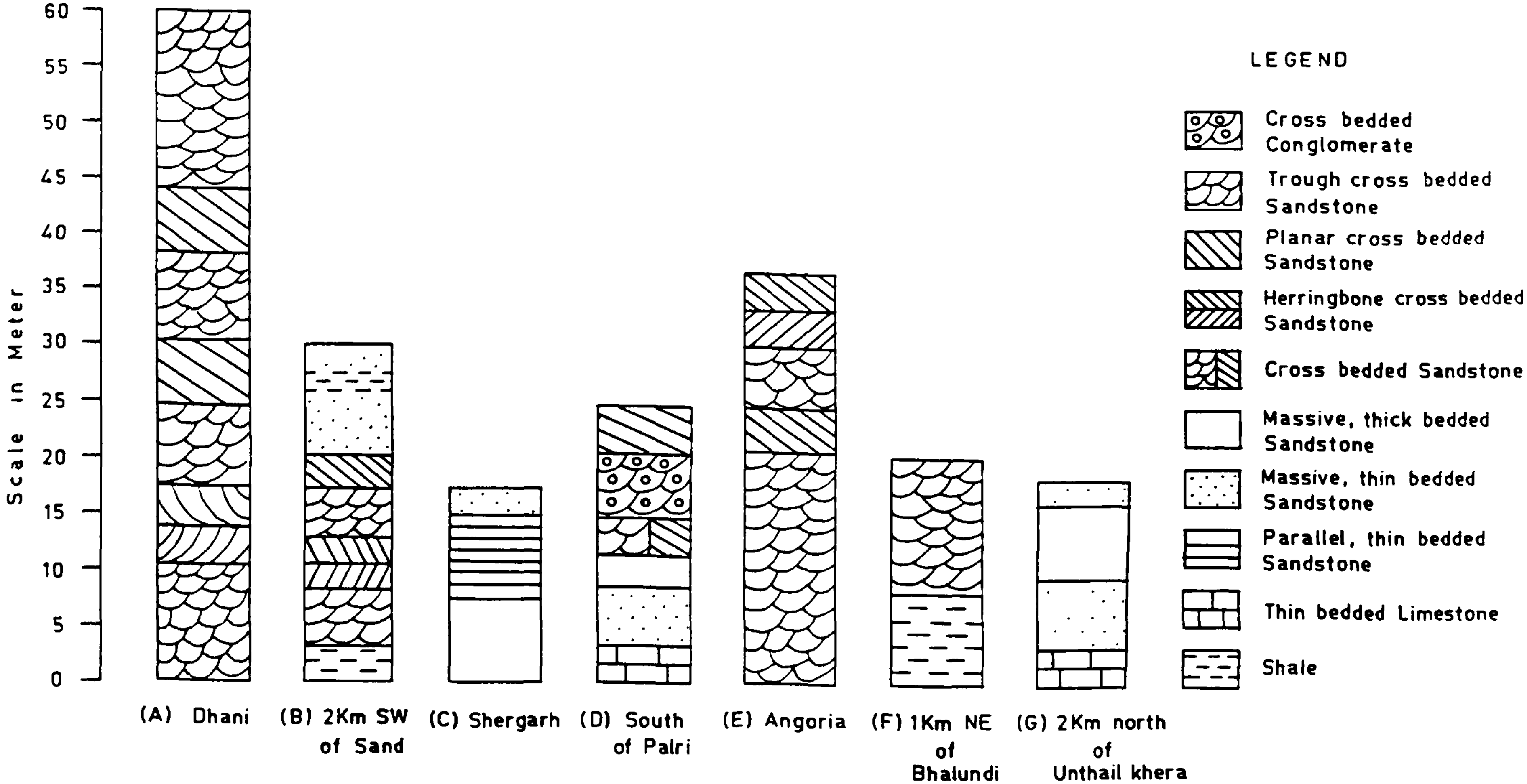

Fig. 6 Stratigraphic sections of Sawa Sandstone Formation measured at Dhani (A), 2 Km SW of Sand (B), Shergarh (C), south of Palri (D), Angoria (E), 1 Km NE of Bhalundi (F) and 2 Km north of Unthail khera (G).

Binota to east of Bhagwanpura. The Sawa Sandstone is generally overlies conformably on Bhagwanpura Limestone having sharp contact but at few places namely west of Binota and north of Kesarpura where due to folding and faulting, Bhagwanpura chert and cherty guartzite occurs as bouldery rocks at the base of Sawa Sandstone.

The Sawa Formation is attained its maximum thickness about 60m at Dhani in north and minimum thickness (5m) at Pagara. The dips range 20-50^{o} towards east or south east but at places westerly dip. This formation was referred to as Sawa Grits by Heron (1936) who thought it to be less metamorphosed facies of the Delhi system. The Sawa Sandstone is overlies the stromatotitic Bhagwanpura Limestone which is of Lower to Middle Riphean age (1000 to 1300 m.y.) (Prasad, 1984).

Eight stratigraphic sections were measured at Dhani, 2km south west of Sand, Angoria, Shergarh, South of Palri, 1km north east of Bhalundi, Binota and 2km north of Unthail Khera to determine the vertical and lateral relationship with the underlying and overlying lithology and sedimentary structures (Fig. 6 and Fig. 4A).

About 1km south west of Palri, a broad outcrop of conglomeratic coarse sandstone forms a small plateau on the summit of which they are excellently exposed, lying with dips upto 17^{o} in both east and west directions. About 24m thick sequence (Fig. 6D) is exposed in a westward facing cliff. At the base the Bhagwanpura Limestone occurs which gradually pass into thin bedded shaly sandstone which in turn overlain by 9m thick bedded sandstone. The sandstone is massive, thin bedded,

PLATE 3

Fig.1

Fig.2

P L A T E - 3

Fig. 1 Photograph of thin-bedded, very fine grained to calcareous sandstone; Sawa Formation.

Fig. 2 Photograph of cross-bedded, coarse grained sandstone showing cross bedding in coset; Sawa Formation.

PLATE 4

Fig.1

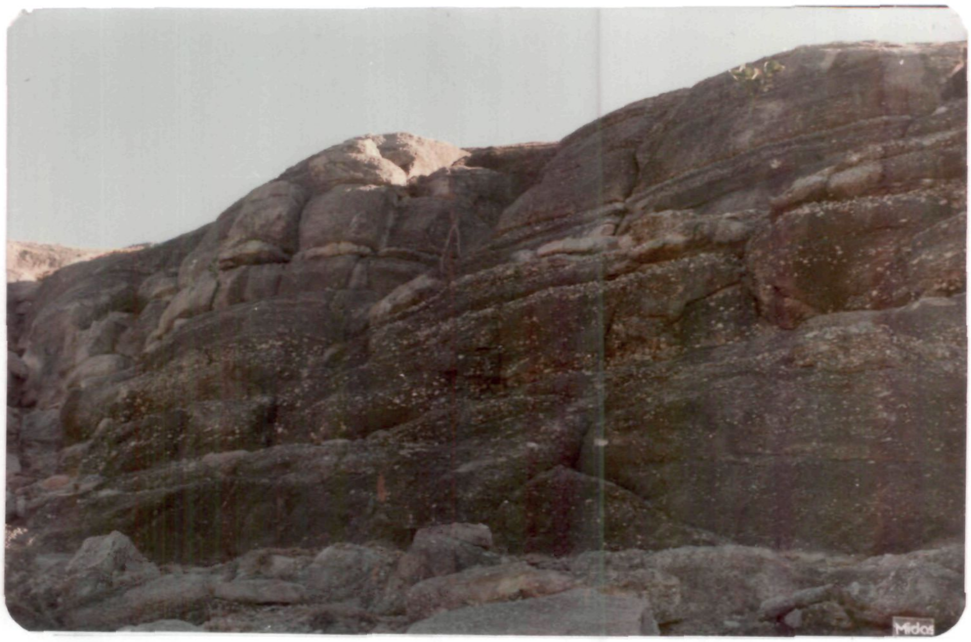

Fig.2

P L A T E - 4

Fig. 1 Photograph of conglomeratic pebbly sandstone, showing subangular to subrounded pebbles supported by sandy matrix; overlying unit is a massive, coarse grained sandstone; Sawa Formation.

Fig. 2 Photograph showing sequence of thick, coarse grained sandstone; Sawa Formation.

very fine grained, feldspathic and calcareous in nature (Plate 3, Fig. 1). But in upper part it is massive, medium grained and thick. The thickness of the individual bed varies from 0.5cm to 10cm. The next 3m thick, cross bedded, medium grained and grey coloured sandstone is exposed. The trough and planar cross beds occur in coset (Plate 3, Fig. 2). The sandstone is overlain by 5m thick sequence of conglomerate. The pebbles in conglomerate are ill defined, ranging in size from 0.3 to 10cm with subangular to subrounded almost entirely of white quartz and embedded in the cherty cements (Plate 4, Fig. 1). Due to coarseness of the deposit, cross bedding is only obscurely seen. Higher up in sequence about 4m thick coarse grained sandstone occurs. The sandstone is thick bedded, massive and occasionally cross bedded, grey in colour and as we go higher up in the sequence it becomes gritty in nature. The thickness of the individual bed ranges from 25cm to 1m.

From south west of Sand to Angoria, the Sawa Sandstone occurs in domed hill with synclinal dip in the range of 15 to 30°. In the western limb of domed hill from Kesarpura to Angoria (Fig. 6E) the regularly bedded 37m thick Sawa Sandstone is well exposed conformably over the Bhagwanpura Limestone Formation with easterly dip in the range of 20°. The base of the Sawa Sandstone rest directly upon the chert and cherty quartzite of Bhagwanpura Formation. The sandstone is thick bedded, massive, cross bedded, coarse to fine grained and grey in colour. Mostly trough type cross bedding occurs in large scale coset but planar type also occur locally. The thickness of the bed is 10cm to 1m thick. At Angoria (Fig. 6E) in the upper part of sandstone, the herringbone cross bedding occur at places.

But in the eastern limb of domed hill, from southwest of Sand to east of Angoria, the Sawa Sandstone conformably overlies the Khardeola shale. About 2km south west of sand in the eastern limb of domed hill, the sequence of about 30m thick Sawa sandstone is well exposed (Fig. 6B). The base of the sequence, about 18m thick sandstone overlies the Khardeola shale with gradational contact. The shale is red in colour and occur as traces. The sandstone is blackish grey, thick bedded, medium grained and cross bedded but at places show herringbone cross bedding. Each sandstone bed is 50cm to 150cm thick. Higher up in sequence, 11m thick, massive, coarse to medium grained, greyish white gritty sandstone occurs. The upper part of the sandstone is marked by the presence of shale intercalations.

The Sawa Sandstone from Angoria to Bhalundi form the low ground with Bhadesar Quartzite. The Sawa Sandstone near Sankhlon Ke Dhani (Fig. 6F) is lying conformably over the dark brown to greenish shale with sharp contact at low angles, facing ridges of vertical Bhadesar Quartzite. However, 10m thick shale show high dips.

Sawa Sandstone reappears further west of Binota and occurs conformably over the Bhagwanpura rocks in the discontinuous outcrops upto east of Bhagwanpura (Fig. 4A) Here sandstone is trough cross bedded, thick bedded, greyish white to pinkish white with 15 to 20m in thickness. But away from

Binota towards Bhagwanpura, Sawa Sandstone with decreasing thickness is passes into massive, yellow to pink bouldery outcrops, which does not show dip and strike.

At Dhani, the Sawa Sandstone has maximum thickness of about 60m. Here whole sequence is cross bedded and at places show herringbone cross bedding (Fig. 6A). At Shergarh and 2km north of Unthail Khera the Sawa sandstone is about 17m thick (Fig. 6C & 6G). Here sandstone is thin to thick bedded, massive and cherty in nature. At Unthail Khera, the sandstone is lies conformably over the thin bedded Bhagwanpura limestone.

In general, the Sawa Sandstone is mainly medium to coarse grained, massive, thick bedded and at places conglomeratic. The individual beds is ranging in thickness from 0.5 to 2.5m and show well developed cross bedding. In sandstone mostly trough type cross bedding is recognised in set to coset. At a few places such as Dhani, Angoria and south west of Sand (Fig. 6) herringbone cross bedding are well recognised. The medium to coarse grained sandstone is ash grey in colour and due to gritty in nature through out the area it consists of rounded to subrounded grains of quartz and feldspar in 0.5 to 2mm in size (Plate 4, Fig. 2).

The fine to very fine grained sandstone generally overlies the medium to coarse grained sandstone and about 2 to 8m thick but at places due to folding and faulting it is overlain by medium to coarse grained sandstone. It is siliceous, cherty, thin bedded, generally grey, some times yellowish pink in colour and at places, stained brown purple.

It is well exposed only in a few section and is fairly persistent between Dhani and Pagara (Plate 11, Fig. 1).

PALRI SHALE

The Palri Formation is comprised of shale and Porcellanite, lies conformably over the Sawa Sandstone having high dips in the range of 25 to 62^{o}. At Palri where it lies unconformably over the stromatolitic Bhagwanpura Limestone. The porcellanite is thin even bedded and lies in the basal part of the Palri formation. The individual bed ranges in thickness from 3cm to 6cm and the maximum thickness of porcellanite is 20m at Parli. It is whitish grey, pale yellow, pale green and is stained bluish purple at places. It is siliceous, very fine grained, hard and compact (Plate 12, Fig.1).

The Palri shale lies over the porcellanite with a gradational contact and are well exposed along the eastern side of the main Sawa ridge from north of Unthail Khera to Dhani and continue up to near Chittorgarh. The shale is attained a maximum thickness (60m) at Palri where it well developed and minimum at Tejpura Ki Dhani (5m). It is thinly bedded and closely jointed, whitish grey, greenish grey, yellowish in colour with grey, pinkish ad purplish bands at places. Palri shale in upper part contains lenticular fine grained sandstone at few places such as Palri (Plate 12, Fig.1) and Pagara. The sandstone intercalation are massive, thick bedded and blackish in colour.

Lasrawan Group

The Lasarwan Group lies conformably over the Sand Group and contain Kalmia Sandstone and Binota Shale. The group contain arenaceous and argillaceous rocks.

KALMIA SANDSTONE

This is a basal formation of the Lasrawan group. It is named after the village Kalmia in south of the area. The formation is consist of sandstone with intercalation of shale. It unconformably overlies the Bhagwanpura Limestone. In the south of the area, about one kilometre east of Kalmia, thin beds of fine to very fine grained sandstone occur with shale intercalation. The sandstone is dark green, greenish brown to pale brown in colour, hard and compact in nature with high dips (25 to 70^{o}). The shaly intercalation are olive green in colour. The Kalmia Sandstone passes upwards into Binota shale with gradational contact. The total thickness of formation is about 15m.

BINOTA SHALE

Binota Shale overlies conformably on the Bhagwanpura Limestone and Palri shale. At the contact the Binota Shale have become siliceous. The formation comprises predominantly of shales with siltstone and sandstone intercalation in the upper part. The shale is calcareous and carbonaceous in the lower beds. They also contain occasionally thin ferruginous bands. The shale is typically olive green, pinkish grey and locally fawn or brown. The shale are thinly bedded, at places, arenaceous and well laminated, with silty intercalation (Plate

PLATE 5

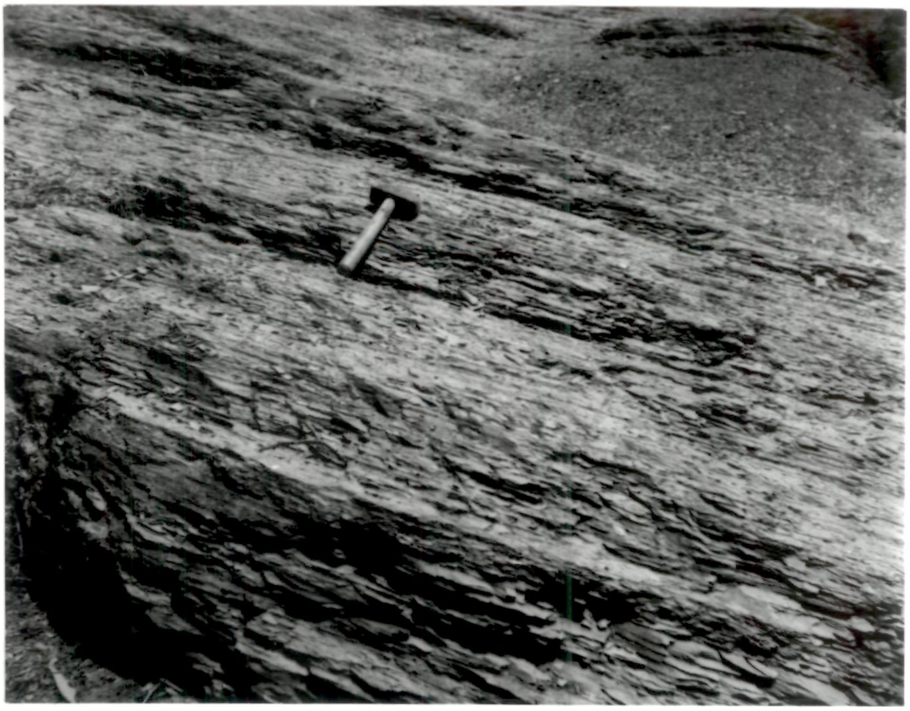

Fig.1

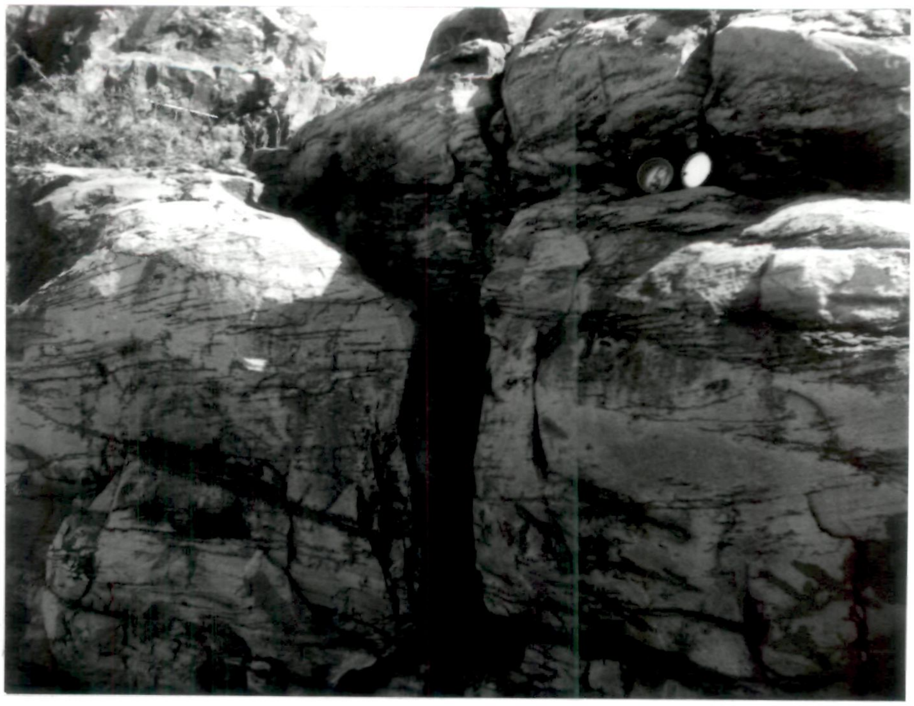

Fig. 2

P L A T E - 5

Fig. 1 Photograph of thin bedded shale showing intercalation of siltstone; Binota Formation.

Fig. 2 Photograph of Trough cross-bedded sandstone (St) facies showing upward decrease in cross bed thickness; Jiran Formation.

5, Fig. 1). The siltstone is generally pale green and occur as lenses, it is reddish brown where ferruginous and contain large hard concretions. Towards the top, white arenaceous shale are found.

The shale is generally hard and fragile, breaking into splintery pieces. Shale outcrops are scanty and the beds show mostly easterly low dips. The shale form the low ground and the thickness could not estimated. According to Prasad (1984) the thickness can be considered of the order of 160m.

Khorip Group

This group is the top most group of Lower Vindhyan rocks of Rajasthan and named after the village Khorip where all the formation are well exposed. This group is consists of Khori-Malan Sandstone at the base, followed by Jiran Sandstone, Bari Shale, Nimbahera Limestone and Suket Shale formations successively overlying Binota Shale of Lasrawan group with an local unconformably in Khori-Malan syncline area. The group is mainly argillaceous to calcereous and about 382m thick.

KHORI-MALAN SANDSTONE

It is a basal formation of the Khorip group and named Khori-Malan Sandstone after the two villages where it is well exposed as outcrops. The Khori-Malan Formation is consist mainly of fine to medium grained sandstone with thin boulder bed occur in upper part at few places. The Khori-Malan Sandstone is exposed along the two ridges which encircling the

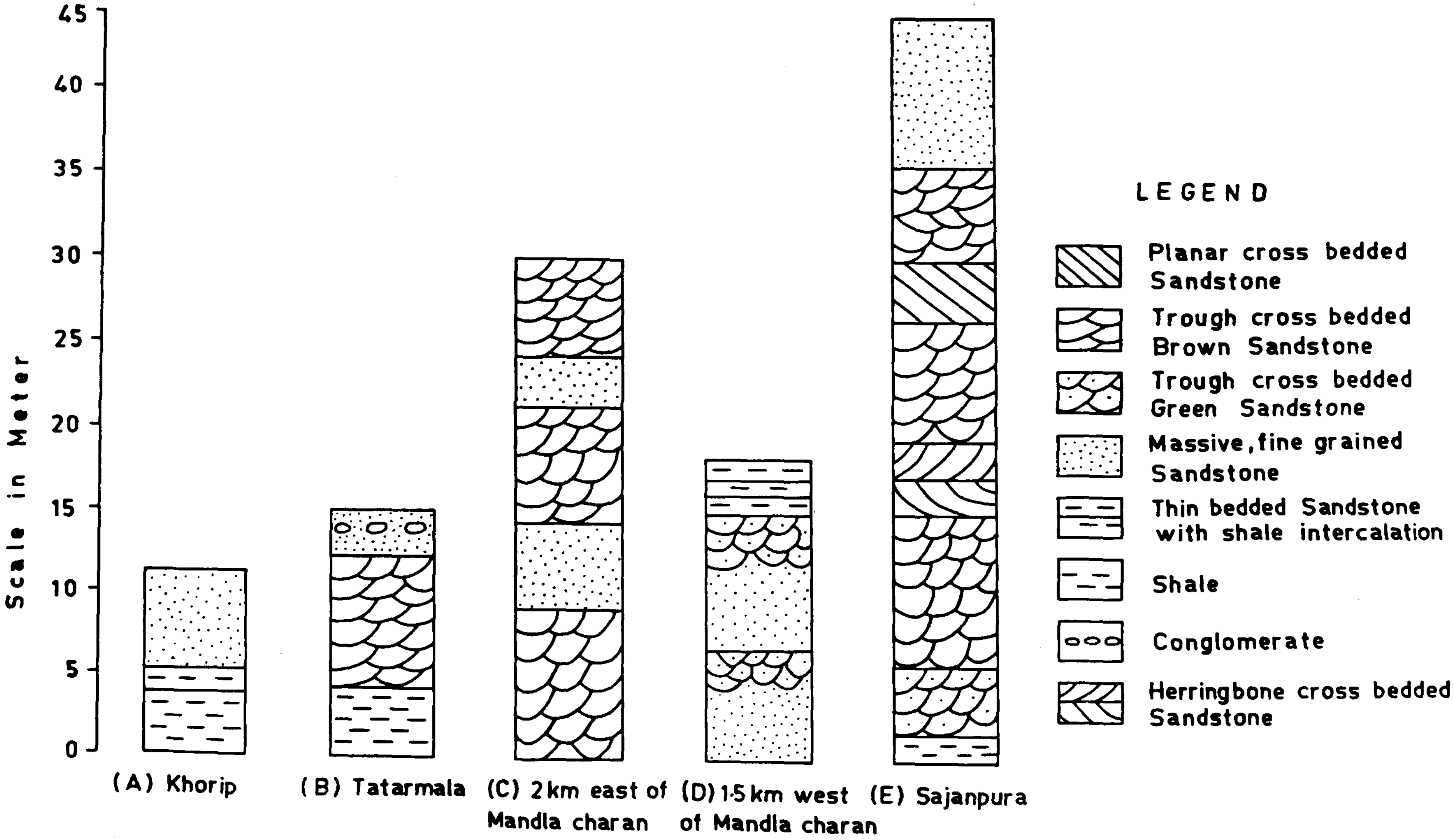

Fig.7 Stratigraphic sections of Khori-Malan Sandstone Formation measured at Khorip (A), Tatarmala (B), 2 km east of Mandla charan (C), 1·5 km west of Mandla charan(D) and Sajanpura (E).

NNW-SSE trending synclinal basin. These ridges of sandstones is running from north west of Barvara to Khorip (as western limb of synclinal basin) and then turning east towards Malan, 2km east of Malan to Gura Khera (as eastern limb of synclinal basin). In this synclinal basin, the Khori-Malan Sandstone occur as ridge, lies mostly conformably over the Binota Shale with dip 8 to 30^{o} and is overlain conformably by Bari Shale, and Nimbahera Limestone Formation with decreasing dip or nearly horizontal towards the centre of the syncline. The western ridge (limb) of syncline has low thickness (average 10m) of sandstone where as eastern ridge trending north-south, has average thickness or height of about 35m.

Five stratigraphic sections were measured at Khorip, Tatarmala, east and west of Mandla Charan and Sajanpura with vertical and lateral relationship establish with lithology and internal sedimentary structures (Fig. 7).

On the western ridge of the syncline the Khori-Malan Sandstone has thin conglomerate bed, consist pebbles of chert, quartz and quartzite, exposed from Tatarmala to Khorip at near top of it. At Tatarmala, about 15m thick sequence of Khori-Malan Sandstone is measured (Fig. 7B). In the basal part of sequence about 4m thick Binota Shale is exposed. The shale is reddish to yellowish in colour. Above this comes about 8m thick, dark reddish, thick bedded, fine grained cross bedded sandstone. The contact of sandstone and shale is gradational. Each sandstone bed is 50cm to 1m thick. Higher up in sequence is about 4m thick coarse grained sandstone with near its top a thin bed of conglomerate is formed the top most outcrop. The sandstone is massive, pale yellow to greenish purple in colour. The conglomerate bed is consist of subrounded to rounded pebbles of chert, and quartzite set in a sandy martix with shale fragments. This sequence is again followed upwards by younger purple Bari Shale and then come 12m thick purple Nimbahera Limestone and then the grey Nimbahera Limestone dipping at a lower than the underlying beds as the dip decreases to nearly horizontal towards the centre of the syncline.

Towards Khorip the conglomerate bed becomes very thin and may in places be absent and the conglomerate grades into coarse ferruginous sandstone with pebbly layers. At Khorip the sequence of Khori-Malan sandstone (Fig. 7A) is essentially the same as just described (Fig. 7B). About 3m thick shale occur at the base with thin bedded, massive, fine grained sandstone rest directly on them. After that about 6m thick, dark green, fine grained, thick bedded, massive sandstone form the top most outcrop of the ridge. Each sandstone bed is 40cm to 1m thick. This is again followed up by thin bedded Bari shale and Nimbahera Limestone.

On the Khorip lobe, about 1.5km west of Mandla Charan, the Khori-Malan Sandstone is again exposed. Here the sequence is about 18m thick (Fig. 7D). At base, 7m thick fine grained, yellowish green sandstone is measured. The sandstone is massive, thick bedded and show poor large scale cross bedding. After that about 8m thick, dark green to whitish grey, fine to medium grained sandstone is exposed. The sandstone towards top is whitish grey which show poorly cross bedding but lower dark green variety is massive. Higher up in sequence, about 3m thick fine grained, thin bedded sandstone with intercalation of shale is formed the top outcrops. The sandstone and shale are massive and pale green to dark brown in colour.

The Khori-Malan sandstone is well exposed with westerly dip in the range of 5 to 54^{o} along the eastern ridge of the synclinal basin, trending north-south strike, running from about 2km east of Mandla Charan to Barvara in south of the area. On the northern end of this ridge near east of Mandla Charan, the Khori-Malan sandstone is exposed in broad domed hill with synclinal high dip (25 to 54^{o}). In this domed hill, the thickness of sandstone is decreases from eastern side (about 40m) to western side (about 20m) (Fig. 7C). Here in sequence from bottom to top, thick bedded, cross bedded to massive sandstone is exposed. The sandstone is white, dark brown to green in colour and show mostly large scale trough cross bedding.

At Sajanpura, the Khori-Malan sandstone is attained maximum thickness (about 45m) (Fig. 7E). Here at base about 5m thick dark green, fine grained, cross bedded sandstone is exposed over the Binota Shale with gradational contact. After that about 30m thick, medium grained thick bedded, cross bedded, reddish grey to whitish grey sandstone is conformably lies over the dark green sandstone. Here each sandstone bed is 70cm to 1.5m thick. The sandstone show mostly large scale trough cross bedding which occur in set to coset. But at places herringbone cross bedding is also recognised. Higher up in sequence about 5m thick, massive, coarse to medium grained sandstone is form the top most outcrop of the ridge. Here sandstone is brownish white in colour and do not show any internal structure.

In the same eastern ridge, at Barvara the Khori-Malan sandstone has nearly the same thickness and sequence as just described at Sajanpura. But here sandstone show both trough and planar type cross bedding which occurs in set to coset. The sandstone at places is also show herringbone cross bedding.

In general, the Khori-Malan sandstone is medium to fine grained, massive and cross bedded. The sandstone is dark green, pale brown, whitish pink in colour and show generally large scale trough cross bedding but at places it show herringbone structure. Thin conglomerate bed is exposed in upper part of sandstone only in western ridge of the syncline from Tatarmala to Khorip.

Khori-Malan Sandstone was originally referred to as Binota Basal Conglomerate (Rec. GSI Vol. 44, part-I, P.29, 1919) but later Heron (1936) called it Khori-Malan Sandstone and considering it as basal Vindhyan. Now Prasad (1975) termed it as Khori-Malan Conglomerate and is a basal member of the Jiran sandstone formation. But after detailed study of it in the area and field evidences as stratigraphic sections, the author follow Hereon (1936) classification and retained it as separate Khori-Malan Sandstone Formation.

JIRAN FORMATION

Jiran Sandstone was originally described as "Delhi Quartzite" by C.A. Hacket (1881). Heron (1936) correlated it with Delhi System. But it does not particularly resemble with Alwar Quartzite of Delhis and there is no regional unconformity separating it from the underlying lithounit as described earlier by Heron (1936). The name of formation was taken from village Jiran (south of study area) where it is well developed.

Jiran Sandstone conformably overlies the Binota Shale, except from Khorip to Barvara where along the western margin of an elongated syncline, the Khori-Malan Sandstone occurs at the base. The Jiran Sandstone occurs in the long ridge from Bamaniya to south of Bari, forming eastern limb of anticline, the western limb of Khori-Malan Sandstone runs roughly north-south from 2km east of Mandlan charan to near Gura Khera with Binota shale in between. Isolated ridges are also recorded in the south east of the area at Sigri, south of Khera, Nersa Kheri, between Margivi and Sarlai which covered by Bari shale. The Jiran Formation is composed of fine to very fine grained sandstone with intercalation of shale at places. In area, the maximum 24m and minimum 10m thickness of the formation are recorded at Bari and south of Khera respectively. The general dip of Jiran Sandstone is easterly at 5 to 50° but due to folding at places it is westerly.

Four stratigraphic sections were measured at Bari, 2km south of Bamaniya, Sarlai and Bamaniya with vertical and lateral relationship establish with lithology and internal sedimentary structures (Fig. 8).

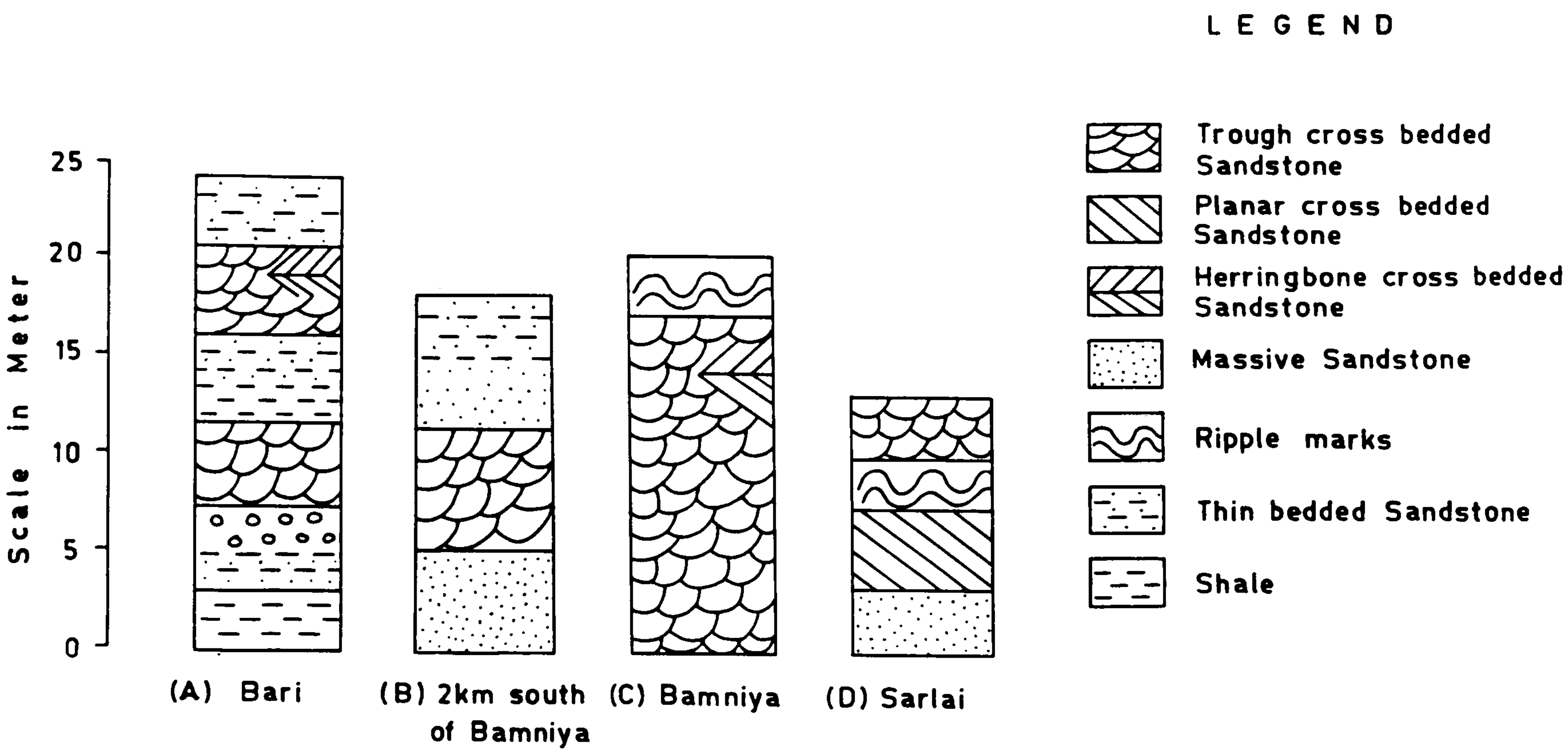

Fig. 8 Stratigraphic sections of Jiran Sandstone Formation measured at Bari (A), 2 km south of Bamniya (B), Bamniya (C) and Sarlai (D).

At Bari, the Jiran Sandstone is well developed and attained thickness of about 24m (Fig. 8A). Here sandstone form anticline with dip range 10 to 20°. In the basal part 2m thick shale is exposed. The shale is pinkish brown to yellowish green in colour and contain beds of bluish sandstone. Higher up in sequence is about 5m thick to thin bedded, massive sandstone. The contact between shale and sandstone is gradational. The sandstone at base is fine to very fine grained thin bedded, whitish grey in colour but in upper part it is very coarse grained, jointed, massive, pinkish brown to pinkish white. Higher up in sequence about 4m thick, pinkish brown to pale grey, trough cross bedded sandstone is exposed. The sandstone is fine to medium grained but at places it is coarse grained. The sandstone beds are 15 to 60cm thick, followed by about 5m thick sequence of pinkish brown shale, which gradually passes into thin bedded sandstone. About 4.5m thick, fine to very fine grained sandstone overlies the thin bedded sandstone. The sandstone is pinkish grey to pinkish brown with mostly large scale trough cross bedding which occur in set to coset (Plate 5, Fig. 2 & Plate 6, Fig. 11) and form the herringbone structures. The sandstone bed is 10cm to 50cm thick. Higher up in sequence occurs about 3.5m thick fine to very fine grained, thin bedded, massive sandstone. The sandstone is pale pinkish in colour about 2 to 7cm thick, and the thickness of the individual bed ranges from 2 to 7cm.

About 2km south of Bamaniya on the eastern limb of the anticline, 18m thick sequence of Jiran Sandstone is exposed (Fig. 8B). The basal part comprised of about 5m thick fine grained, thin bedded sandstone. The sandstone is massive and pinkish white in colour. The sandstone is gradually passes into 6m thick, fine to very fine grained, pinkish brown sandstone. The sandstone bed is 60cm to 1.5 thick and show mostly large scale trough cross bedding occuring in set and coset. Higher up in sequence about 7m thick fine to very fine grained, massive, pinkish brown sandstone occurs. The grain size decreases upward and the bedding characters are also changed. The thickness of the bed is also decreases.

At Bamaniya about 20m thick sequence of Jiran Sandstone was measured (Fig. 8C). The sandstone is very fine to fine grained, thick bedded and marked by the presence of trough cross beds. The sequence show three distinct division. In the lower division sandstone is hard and compact, pale grey mottled with deep purple. The middle one is deep purple and grey similar to the lower, but containing nearly as much purple as grey and the upper division is only deep purple or pinkish brown in colour. In the upper division of the sequence the sandstone show well developed symmetrical as well as asymmetrical ripple marks (Plate 15, Fig. 2 & Plate 16, Fig. 1) and at places large scale trough cross bedding forms the herringbone strucutre.

In the south east of the area, at Sarlai, about 12m thick sequence of Jiran Sandstone is exposed (Fig. 8D). The basal part of the sequence is consist about 2.5m thick, massive, dark pinkish brown, thin bedded sandstone. This sandstone is gradually passes into 5m thick bedded, cross bedded sandstone. The sandstone show planar type of cross bedding, followed by 4.5m thick, fine grained, thick bedded, pink to pinkish brown sandstone form the top most outcrop. Here sandstone show symmetrical ripple marks and trough cross bedding. Each bed ranges in thickness from 10 to 50cm.

In south east of the area, Jiran Sandstone is also well developed at Sigri, Nersa Kheri, south of Khera and east of Marjivi with anticlinal or easterly dip in the range of 5 to 50^{o}. The sandstone is thin to thick bedded, fine grained, blackish grey, greyish pink, greyish white with black spot and massive in nature. Each sandstone bed is 5 to 100cm thick and show mostly large scale trough type cross bedding.

In general, the Jiran Formation is consist mainly of sandstone with shale intercalation at some places. The sandstone is pinkish grey, whitish pink, pinkish brown, greyish brown, blackish grey and purple in colour and show regular joints. The sandstone is generally fine to veryfine grained but at some places coarse grained, thin to thick bedded and show large scale cross bedding mostly of trough type and ripple marks. The Jiran Sandstone mostly show gradational contact with underlying Binota Shale. It is also overlain conformably by Bari Shale.

BARI SHALE

Middlemiss and Jones (as described by Hayden, 1914) called it as Nimbahera Shale. In a synclinal basin from Khorip to Vijaypura, Bari Shale unconformably overlies the Khori-Malan Sandstone and overlain by Nimbahera Limestone. From Bamaniya to Bari, the Bari shale rests conformably on the

Jiran Sandstone. From Doriya to Joravar Singh Ka Khera in north, it overlies the Binota Shale with gradational contact.

The shale is thinly bedded with parallel laminations, showing at places colour banding. It is typically purple, yellowish green and reddish brown in colour, but at some places it is pinkish red with mica flakes. It is fissle, splintery and breaks into fusiform pencils. At places it is arenaceous in the lower part and calcareous towards the top. North of Mundalan Charan, Binota Shale overlies the Bari shale, where flaggy argillaceous sandstone beds grades into arenaceous shale. Outcrops of Bari shale is few. It is well developed at Daru Nadi near Chhoti Kotri and south east of the area (Plate 13, Fig. 2). Bari Shale show mostly easterly low dip in the range of 5 to 24^{o} but at places westerly dip. The Bari Shale is about 45m in thickness (Heron, 1936).

NIMBAHERA LIMESTONE

The tern Nimbahera Limestone is named from the town of Nimbahera where this formation is well developed. The Nimbahera Limestone, occurs from Satkhanda in north to Nimbahera and to east of Chhoti Kotri in the south east of the area conformably overlying the Bari shale with gradational contact and overlain conformably by Suket shale.

It is often well exposed with a general north-south strike and low dips and largely quarried in many places especially near Binota, Khorip, Phalwa, Javod, Lakshmipura and small quarries for local purposes occur almost every place where it crops out. In area, the outcrop of Nimbahera

Limestone are scanty due to its subhorizontal to horizontal disposition. The limestone is therefore seen only along nala and quarry sections. But at Lakshmipura and Sagvaria, the outcrop of Nimbahera Limestone is well exposed. At Lakshmipura about 13m thick sequence of limestone is measured. In the basal part, the limestone is thin bedded, massive and greenish grey to purple in colour whereas in upper part thick bedded massive and greenish greyin colour. The limestone bed is 5 to 10cm thick, well laminated and dipping toward east with low dip (less than 10^{o}). At Sagvaria, thickness of limestone about 6m recorded on which this village is situated. The limestone is thick bedded and grey in colour and beds dipping towards north east with dip in the range of 5 to 8^{o}.

The aggregate thickness of limestone is about 148m (Heron 1936). Out of which the lower 10 to 12m thick are argillaceous (Plate 18, Fig. 1), pinkish or pinkish grey. The lower argillaceous limestone is thin bedded, parallel laminated, massive and contain fine silty layers. The lower pinkish limestone generally grades into Bari Shale through calcareous shale. The upper 136m of limestone is usually pale bluish grey, blackish grey or greenish grey with occasional streaks or layers of fawn. It is thick bedded, massive, hard and compact, slabby, noncrystalline, containing common quartz partings and breaks with smooth surfaces. Each bed ranges in thickness from 10cm to over a meter. The limestone bed is consist of fine silt in a carbonate mud in thin layers which exhibit penecontemporaneous deformation. Occasionally rolled elongated pellets and nodules of limestone are seen embedded in these beds. Vermiform burrows, warm tracks and faecal pellets are seen in the lower argillaceous limestone and in the lower most beds of grey upper limestone occurring east of Lasrawan (Mahajan, 1973).

Nimbahera Limestone is fairly high grade limestone and is quite suitable for cement manufacture. This limestone is used by two cement factories, one is Birla Cement Works at Chanderia, about 9km north of Chittorgarh and the other J.K. Cement Works at Nimbahera.

SUKET SHALE

Suket Shale is the upper most formation of the Khorip group and named after the locality Suket in south eastern Rajasthan. Suket Shale is conformably overlies the Nimbahera Limestone. It occurs from east of Satkhanda to Gambhiri Road Railway station along Railway line and extends further eastwards in north east of the area. The formation comprises mainly shale with intercalation of limestone at the base. Heron (1936) estimated the thickness of the formation to be about 120m. As the shale is soft, outcrops are scare. The exposure of Suket Shale are seen along Railway line and Gambhiri Nadi. The shale is generally calcareous and micaceous at the base. It is pale greenish, bluish grey, chocolate brown and dark red in colour. It is hard, fissile and fragile.

CHAPTER - II

LITHOFACIES

Introduction

The term 'facies' has been derived from the latin word facia, implying the external appearance or look of something. It was introduced in geology by Nicholaus Steno (1669). It meant the entire aspect of a part of the earth's surface during a certain interval of geological time (Teichert, 1958). The modern usage was introduced by Swiss geologist Gressly (1838), who used the term to imply the Sum total of the lithological and palaeontological aspects of a stratigraphic unit. Moore (1949) revised the original concept and suggested that the term facies should be considered to 'comprise any areally restricted parts of a designated stratigraphic unit in which physical and/or organic characters differ significantly from those of another part or parts.'

Facies studies have been carried out rapidly during the past two decades with the use of Walther's (1894) classical concept. The occurrence of a facies and its position in a sedimentary sequence has genetic significance. In sedimentary sequences, it is designated by colour, stratification, composition, texture, fossil and primary sedimentary structures. The term 'facies' or more precisely sedimentary facies in a sedimentary sequence may be used in different ways depending upon individual criteria, as in strictly observational sense of a rock body (sandstone facies), in a genetic sense (turbidite facies) and in an environmental sense (fluvial facies). Middleton (1978) stated however that facies will ultimately be given an environmental interpretation. According to Miall (1984a, P.134) the term of facies can also be used in an interpretive sense, for groups of rocks or lithofacies assemblage that are thought to have been formed under a broadly similar depositional environment. In spite of these definitions, a facies can be objectively defined, based on dominant lithotype and associated sedimentary structure, as proposed by Walker et al (1975). Today Sedimentologists most commonly use the word facies to a rock unit that can be characterised by a set of features, such as grain size, geometry and primary sedimentary structure, that distinguish it from other rock units and designate and interprete sedimentary processes and environment of deposition of sedimentary sequence (Anderton, 1985, P.31). According to Reading (1986), 'A facies is a body of rock with specified characteristics'.

Thus, the present status and concept of sedimentary facies have considerably enhanced our understanding of sedimentary environments and sedimentary processes of both recent and ancient deposits. With this in mind, the Lower Vindhyan rocks of study area were carefully examined on each outcrop during the course of field work and the following data were collected in respect of sedimentary facies.

Facies description

In the light of the modern facies concept the lower Vindhyan rocks of Bhadesar-Nimbahera area were carefully examined on each outcrop during the course of field work and

16 lithofacies have been recognised on the basis of lithology, grainsize, primary sedimentary structure and bedding type. These lithofacies were named and coded individually or grouped as associations, following a modified coded scheme of Miall (1978). The lithofacies code consists of two parts, a capital letter of dominant lithofacies, S = Sandstone, F = Shale/ Siltstone, L = Limestone, a lower case letter or letters chosen as a mnemonic of a distinctive grain size/structure as subscript of each lithofacies. The code and description of each lithofacies are given below :

Trough cross-bedded sandstone (St)
Planar cross bedded sandstone (Sp)
Massive sandstone (Sm)
Massive conglomerate (Cm)
Interbedded sandstone and shale (Sl-Fl)
Horizontally bedded to parallel laminated sandstone (Sh)
Laminated siltstone to shale (Fl)
Calcareous shale (Fsc)
Channel sandstone (Sch)
Ripple laminated sandstone (Sr)
Herringbone cross bedded sandstone (S-hb)
Lithofacies A
Lithofacies B
Lithofacies C
Lithofacies D
Lithofacies E

Trough cross-bedded Sandstone (St). - This facies is pale yellow, pinkish white, grey and brown in colour. The sandstone is dominantly medium to fine grained and locally coarse grained. Trough cross-bedding occurs in single set (Plate 6, Fig. 2) to coset (Plate 7, Fig. 1). Individual sets may be separated by plane bed, massive bed or by reactivation surfaces (Plate 7, Fig. 1 & Plate 7, Fig. 2). In vertical section parallel to current flow, foresets are truncated tangentially to the lower bounding surface. The curvilinear foresets run parallel to the basal scored surface. In vertical sections normal to the current direction , traces of foresets are commonly symmetrically curved (Plate 7, Fig. 2). Each large trough cross-bedded set ranges in thickness from 25cm to 1m in Khardeola Formation, 20cm-1.5m in Sawa Formation, 40cm to 2m in KhoriMalan Sandstone and 15cm to 1m in Jiran Sandstone, whereas small scale cross-beds ($<$ 4cm thick, Reineck and Singh, 1980, pp.98, 99) are occasionally seen only in Sawa and Jiran Sandstone (Plate 6, Fig. 2).

The St facies mostly interbedded with fine to medium grained, horizontal bedded sandstone but at places associated with Sp facies (Plate 7, Fig. 2). This facies is well developed at Antail in Khardeola Sandstone; Dhani, Kesarpura, Angoria, Palri, Kantharia in Sawa Sandstone; Sajanpura, Barvara in Khori-Malan Sandstone and Bari, Sarali in Jiran Sandstone. The St facies mostly show a decreasing scale of cross bedding in vertical sections (Plate 5, Fig. 2) but in Khardeola and Sawa Sandstone the St facies show increasing thickness of sets (Plate 7, Fig. 2). The overall cross-bedded sandstone exhibits fining and/or coarsening upward cycles of 5

PLATE 6

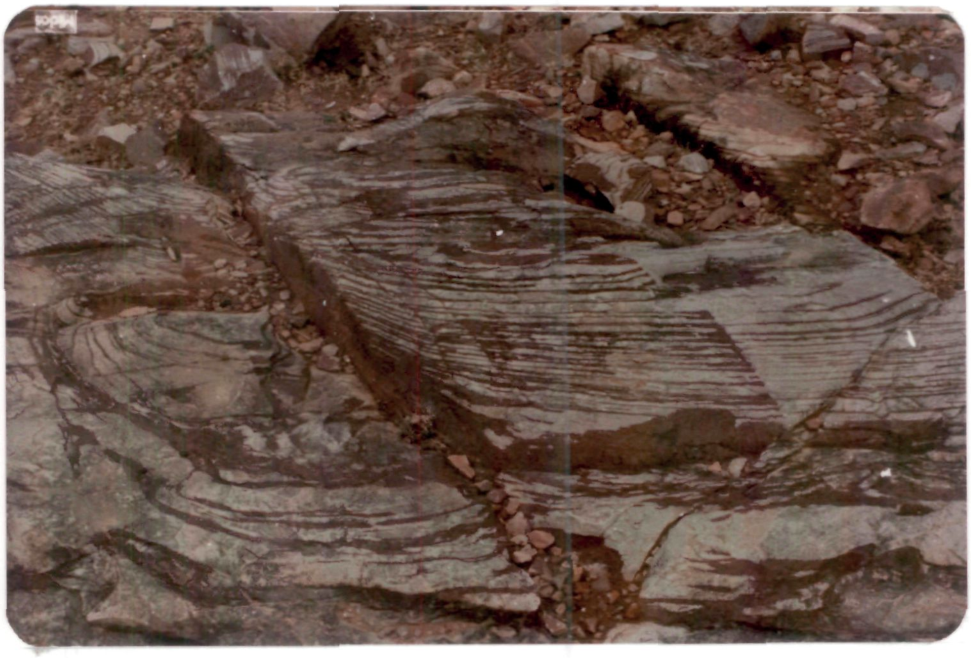

Fig.1

Fig.2

P L A T E - 6

Fig. 1 Photograph of Trough cross-bedded Sandstone (St) facies developed in a-b plane; Jiran Formation.

Fig. 2 Photograph of Trough cross-bedded Sandstone (St) facies showing single set and underlain by Massive Sandstone (Sm) facies; Sawa Formation. Ball Pen (14cm) for scale.

PLATE 7

Fig. 1

Fig. 2

P L A T E - 7

Fig. 1 Photograph of Trough Cross-bedded Sandstone (St) facies, showing coset; Khardeola Formation. Ball Pen (14cm) for scale.

Fig. 2 Photograph of Trough Cross-bedded Sandstone (St) facies, showing upward gradual increase in thickness of cross bed and separated by plane or massive bed; Khardeola Formation.

to 10m thickness on outcrops.

Interpretation. - Trough cross-beds formed by the migration of dunes (Collinson, 1970; Smith, 1971), megaripples (Karcz, 1972; Singh and Kumar, 1974, Reineck and Singh, 1980) and lunate bars (Allen, 1963; Desloges and Church, 1987). Harms et al (1982) described the formation of trough cross-beds by the migration of three dimensional large ripples (dunes and mega ripples) (Ashley, 1990). Small scale cross beds are interpreted as formed by the migration of cuspate ripples where as large scale trough cross-bedding is formed by the migration of cuspate (3D) mega ripples (Hayes and Kana, 1976; Boothroyd, 1985).

Both Sp and St facies display evidence of fining or coarsing upward cycles, with a decrease or increase in scale of cross-bed thickness and corresponding grain size in vertical sections of 2 to 6m thickness.

Fining upward cross-bedded sandstone bodies as found in the study area (Plate 5, Fig. 2) may be attributed to tidal channels or Barrier inlet or intertidal sand body or flood and ebb dominated tidal delta (Land, 1972; Kumar and Sanders, 1974; Hubbard and Barwis, 1976; Barwis and Makurath, 1978; Carter, 1978; Hayes, 1980 and Reinson; 1984 and Einsele, 1992).

However coarsening upward, cross-bedded sandstone also found in the study area (Plate 7, Fig. 2) may be attributed to have formed possibly by migration of lunate mega ripples in Bar, longshore trough and Rip channel facies of oblique Bar-Rip Channel System of Nearshore (Hunter et al, 1979) or

Outer rough and surf zone of Non barred Nearshore (Clifton et al, 1971; Decelles, 1987; Einsele, 1992).

Planar Cross-bedded Sandstone (Sp). - The planar cross-bedded facies (Sp) is associated with trough cross-bedded (St) and massive sandstone (Sm) facies or interbedded with them. The sandstone is very fine to medium grained, locally coarse grained and whitish pink, grey to greyish white and pale brown in colour. Planar cross-beds occur mostly in Single Set (Plate 8, Fig. 1). Each foreset ranges in thickness from less than 5cm to 50cm and length about 10cm to 1.5m and has inclination of 10° to 25°. The facies at places is bounded by gently erosinal reactivation surfaces (Plate 8, Fig. 2). In vertical section parallel to current direction, the foresets are sharply truncated at top and bottom.

Large scale planar cross-beds are developed in the lower part of barrier-inlet or tidal channel deposits or may occur in Bar, longshore facies of Nearshore, Surf zone and Shoreface environment. The smaller scale planar cross-beds consisting of fine sand occur in the upper part of tidal channel deposits as well as flood dominated tidal delta. Foreset Orientation is commonly bimodal directed toward northwest (landward) and southeast (Seaward) but occasional unimodal distribution is also developed directed either north west or south east.

Interpretation. - The small scale planar cross-beds are formed by migration of linear ripples whereas large scale planar cross- bedding is produced both by linear (two

PLATE 8

Fig.1

Fig.2

P L A T E - 8

Fig. 1 Photograph of Planar Cross-bedded Sandstone (Sp) facies, showing single set and overlain and underlain by massive sandstone (Sm); Sawa Formation. Ball Pen (14cm) for scale.

Fig. 2 Photograph of Planar Cross-bedded Sandstone (Sp) facies, showing reactivation surfaces and overlain by massive sandstone (Sm) facies; Khori-Malan Formation.

dimensional) mega ripples and sand waves (Harms et al, 1982; Hayes & Kana 1976 and Boothroyd, 1985 or migration of three dimensional medium subaqueous dunes (Ashley, 1990).

The large scale bidirectional planar cross-beds with reactivation surfaces may be developed in deep channel facies of Barrier inlet or tidal channel deposits are interpreted as due to the migration of tidal channel currents or sand wave deposition under low flow regime conditions in an ebb dominant channel flow. However small scale planar cross-beds in the shallow channel were deposited by flood tidal currents under upper flow regime (Land, 1972; Kumar and Sanders, 1974; Hubbard and Barwis, 1976; Barwis and Makurath, 1978; Carter, 1978; Hayes, 1980; Reinson, 1984; Einsele, 1992). The large scale planar cross-beds may be formed by migration of linguoid megaripples in Bar and longshore trough facies of oblique Bar-Rip channel system of Nearshore (Clifton et al, 1971) or outer rough and Surf zone of Non barred Nearshore (Hunter et al, 1979; Einsele, 1992) or Middle and Upper Shoreface (Campbell, 1971; Land, 1972; Carter, 1978; Reinson, 1984; Einsele, 1992).

Massive Sandstone facies (Sm). - Massive sandstone facies occur as thick bodies or units lacking visible sedimentary structure. Massive sandstone is medium to fine grained locally coarse grained, well to moderately well sorted. The thickness of the individual units ranges from 40cm to 2m. The thickness of Sm facies ranges from 2m to 10m (Plate 9, Fig. 1) and can be traced laterally for a long distance with various colours

PLATE 9

Fig.1

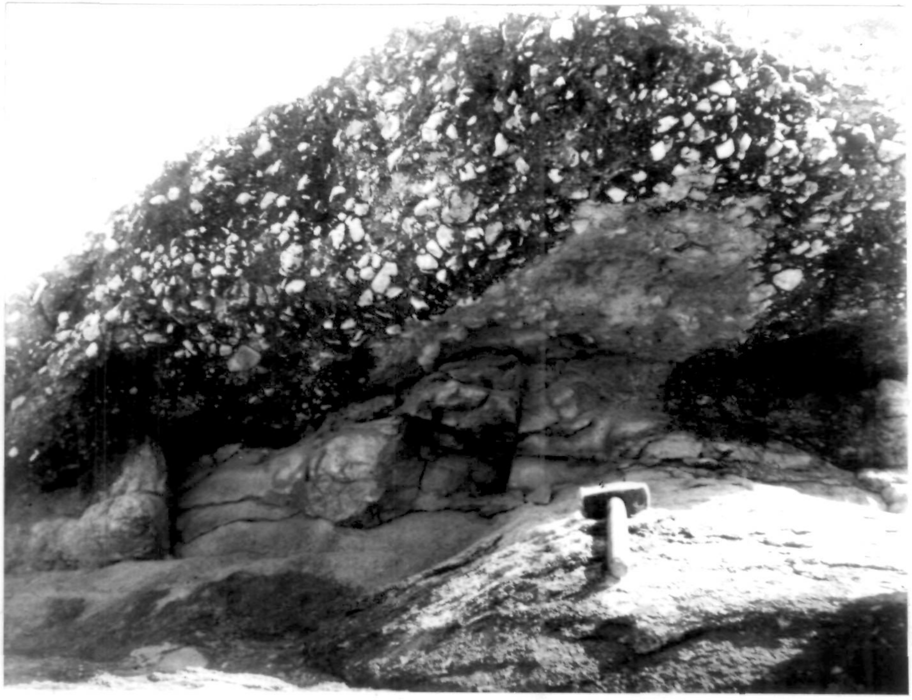

Fig.2

P L A T E - 9

Fig. 1 Photograph of Massive Sandstone (Sm); Khardeola Formation. Hammer (30cm) for scale.

Fig. 2 Photograph of Massive Conglomerate (Cm) facies. Note the underlying unit is a massive sandstone (sm) facies; Sawa Formation.

such as, pinkish white, reddish brown, greenish grey and blackish grey. Massive sandstone facies lies over or interbedded with the St (Plate 6, Fig. 2), Sp (Plate 8, Fig. 1) or Cm facies as outcrop or intercalation in the Khardeola, Sawa and Jiran Formations. The good exposures of the facies are seen at Tejpura, Palri and Bari (Plate 9, Fig. 2).

Interpretation. - The deposition of massive sandstone may be attributed to an increase in flow regime due to local shallowing of the basin floor (Mckee et al, 1967). Fielding (1986) interpreted the massive unit as the product of rapid sediment dumping from high energy flows. Lindholm (1987) described that massive sandstones are formed by certain sedimentary gravity flows which lack a mechanism to produce primary structures or the structures are destroyed by upward movement of pore water or by bioturbation. Massive sandstone, composed of fine to medium grained sediments, may be interpreted as the result of sediment transportation in planar sheets under very high energy conditions (Rust, 1972; Casshyap and Kumar, 1987). The association of Sm with interbedded sandstone and shale (Sl-Fl) facies may represent upper subtidal to lower intertidal environment (Mazzullo, 1978; Klein, 1985).

Massive Conglomerate facies (Cm). - The massive conglomerate facies is earthy yellow to greyish white in colour, occurs locally as thick bodies. Laterally and vertically this facies is embedded in a coarse grained sandstone. The pebbles (1 to 8cm in diameter) including very small ones (2 to 4mm diameter) are generally subrounded to subangular, commonly white to yellowish white and predominantly quartzitic in composition. The voids between clasts are filled with well sorted sand (Plate 9, Fig. 2). This facies is 1 to 8m thick and can be traced laterally for about 10 to 25m depending upon size of the outcrop. The Cm facies are interbedded with medium to coarse grained, massive (Sm) and cross-bedded (St or Sp) sandstone with sharp contact (Plate 10, Fig. 1). The lower and upper bounding surfaces are erosional. The best outcrops of this facies are seen south of Palri in Sawa Sandstone (Plate 9, Fig. 2 & Plate 10, Fig. 1).

Interpretation. - The massive conglomerate facies (Cm) may be interpreted either as shoreline conglomerate due to local longshore current (Leckie and Walker, 1982) or beach conglomerate (Leckie and Walker, 1982). Wright and Walker (1981) and Leckie and Walker (1982) have interpreted such association as having formed by microtidal activity and by longshore redistribution of fluvial gravels probably by longshore currents. The massive conglomerate interbedded with trough cross beds (St) or massive sandstone (Sm) and their substantial thickness (as much as 8m) and their pebble content, such association may be formed in upper shoreface environment (Decelles, 1987; Hart and Plint, 1989; Einsele, 1992).

Interbedded Sandstone and Shale (Sl-Fl). - Thinly interbedded fine grained sandstone and shale facies is very prominent facies occurring through out the Binota, Khori-Malan and Jiran Formations. The fine to very fine grained sandstone or

PLATE 10

Fig. 1

Fig. 2

P L A T E - 10

Fig. 1 Photograph of Massive Conglomerate (Cm) facies, showing sharp contact with underlying massive sandstone. Sawa Formation.

Fig. 2 Photograph of Thinly interbedded sandstone and shale (Sl-Fl) facies. Jiran Formation.

siltstone is occurring as thin beds ranging in thickness from 5cm to 35cm. The contact of massive, horizontally, thin bedded sandstone with shale is sharp to wavy (Plate 10, Fig. 2). This facies ranges in thickness from 2m to 7m and well exposed at Bari and Binota. The predominant sedimentary structure in this facies is subparallel, horizontal, thin bedded, gently dipping beds.

Interpretation. - The Sl-Fl facies suggests fluctuating hydrodynamic conditions. The sandstone represents deposition during the current activities and argillaceous units through suspension load during periods of quiet water conditions. The sedimentologic and lithologic attributes of this facies are interbedded siltstone or very fine grained sandstone and shale, are analogous to those of the lower parts of modern high intertidal flats (Klein, 1967, 1970b and 1971; Kuijpers, 1970 and 1971; Reineck, 1967; Mazzullo, 1978). These interbedded rocks are believed to have been deposited in the lower most intertidal zone : the silts were deposited by high energy tidal current bedload traction whereas the shale represent suspended particles that settled out during slack water periods.

Horizontally Bedded to Parallel Laminated Sandstone (Sh). - The Sh facies is characterised by parallel laminated (Plate 11, Fig. 1) and horizontal bedded sandstone (Plate 7, Fig. 2) but at places it is gently inclined sandstone (Plate 11, Fig.2). Lamination is visible due to differences in grain size, composition and colours. The thickness of each lamina

PLATE 11

Fig. 1

Fig. 2

P L A T E - 11

Fig. 1 Photograph of Horizontally bedded to parallel laminated sandstone (Sh facies); Sawa Formation.

Fig. 2 Characteristic medium grained sandstone (Sh facies), showing horizontal to gently inclined bedding; Sawa Formation.

ranges from 5mm to 1cm. The lower bounding surfaces of horizontal bedded units are, horizontal and parallel. The horizontal bedded and laminated sandstone ranges in thickness from 25cm to 1m and are persistent laterally for a few meters. Lithologically, horizontal bedded sandstone is medium to very fine grained, locally coarse grained. This facies commonly truncates massive or cross-bedded sandstone along a sharp, roughly horizontal contact (Plate 7, Fig. 2).

Interpretation. - Horizontal bedded facies can develop under shallow water condition (Miall, 1977) or as the product of upper flow regime plane bed which develops beneath flow of high velocity or low depth (Reading, 1978; Collinson and Thompson, 1984, P.97). The horizonatal and parallel laminated sandstone, a characteristic of inner planar facies of Swash zone of foreshore beach environment (Hunter et al, 1979; Reinson, 1984; Davis, 1985; Decelles, 1987; Einsele, 1992). Similar associations of Sh facies with St and Sp have been formed under tidal inlets and tidal channel deposits (Coleman and Gagliano, 1964; Elliot, 1974; Tankard and Barwis 1982). Gently inclined or evenly laminated sandstone may be attributed to beach deposits or sand shoals exposed to wall action (Reineck and Singh, 1980, P.120; Decelles, 1987).

Laminated Siltstone to Shale (Fl). - The Fl facies comprises mainly shale with occasional interbeds of lenticular bedding of fine grained sandstone with roughly horizontal sharp contatct (Plate 12, Fig. 1). The shales are thin bedded (1mm to 1cm), laminated, hard and compact and breaks along joints

PLATE 12

Fig. 1

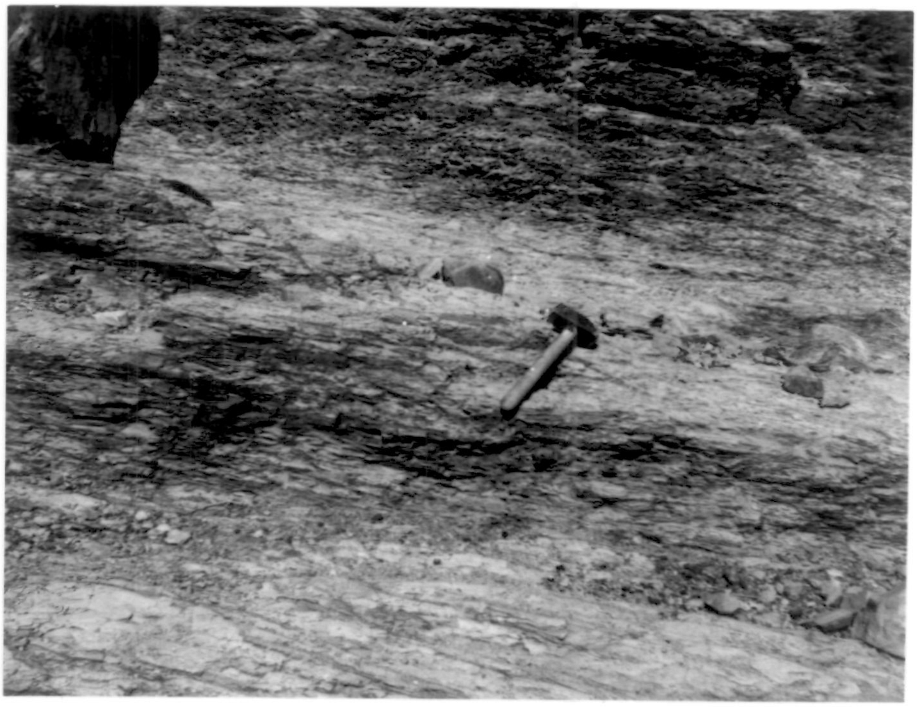

Fig. 2

P L A T E - 12

Fig. 1 Photograph of Laminated siltstone to shale (Fl) facies, showing interbeds of lenticular bedding of fine grained sandstone with sharp contact; Palri Formation.

Fig. 2 Photograph of calcareous shale facies (Fsc), showing finely interlaminated (mm scale) argillaceous shale; Jiran Formation. Hammer (30cm) for scale.

giving rise to rhombic pieces. The sandstone is hard and compact, black in colour, siliceous in nature and occurring at Palri.

The laminated siltstone facies is dull white, pale yellow or greyish white in colour, thinly laminated and closely jointed. The Fl facies mostly truncates Sm or Sh facies along a sharp, roughly horizontal contact. The Fl facies is 4-15m thick and extend laterally for a long distance.

Interpretation. - The Fl. facies are believed to have been deposited in the lower most intertidal zone (Mazzullo, 1978). The silt bed were laminated and deposited by high energy tidal current bed load traction where as the shale represents suspended particle that settled out during quite water periods (Klein, 1985). The sudden change in current velocity and no sequential order in the succession are reflected by sharp boundaries between the two lithology and characteristics of tidal deposits (Terwindt, 1975).

The development of lenticular bedding requires conditions of current or wave action depositing the sand alternating with slack water conditions when silt and clay is deposited (Reineck, 1960 a, b). The sand lenses are made up of foreset laminae of current ripples. When the ripples migrate (with a zero angle of climb) a clayey substrate and supply of sand or silt is limited, the isolated ripple trains as lenticular bedding may be preserved (Lindholm, 1987). Unsteady sediment transport associated with the turbulent bursting process formed the lenticular bed (Bridge and Best, 1988).

Klein (1975) described that lenticular beds are the characteristic of modern tidal Flats.

Calcareous Shale facies (Fsc). - The Fsc facies consists mainly calcareous shales with occasional lenses or lenticular bedding of calcareous siltstones (Plate 12, Fig. 2 & Plate 13, Fig. 1). The shales are thin bedded to massive, micaceous, splintery and dark green to dark pinkish red but occasionally pinkish yellow in colour. The thickness of individual beds ranges from 1mm to 1.5cm (Plate 12, Fig. 2). The shale (Fsc) facies is 1 to 8m thick and can be traced laterally for a long distance. The Fsc facies may lie either below Sp, Sm and St facies or interbedded with a gradational or sharp contact in the lower part of Jiran Formation. However in Bari Formation, the character of facies in upper part are similar to the character of lower Nimbahera Limestone and the lower part of the facies shows characters similar to Binota shale. Softness and rapid erodibility have resulted in large scale disappearance of this facies from outcrops but it is well exposed along Daru Nadi near Chhoti Kotri in Bari Formation (Plate 13, Fig. 2). The surfaces of the shale layers commonly are marked by desiccation cracks. Some Flat pebble siltstone is occasionally seen in shale.

Interpretation. - The lithologic and structural aspects of these facies are similar to those of modern and ancient high tidal flats (Klein, 1967a, 1970b; Reineck, 1967; Kuijpers, 1970; Mazzullo, 1978; Boothroyd, 1985). The finely interlaminated (mm scale) argillaceous shale and siltstone with lenticular

PLATE 13

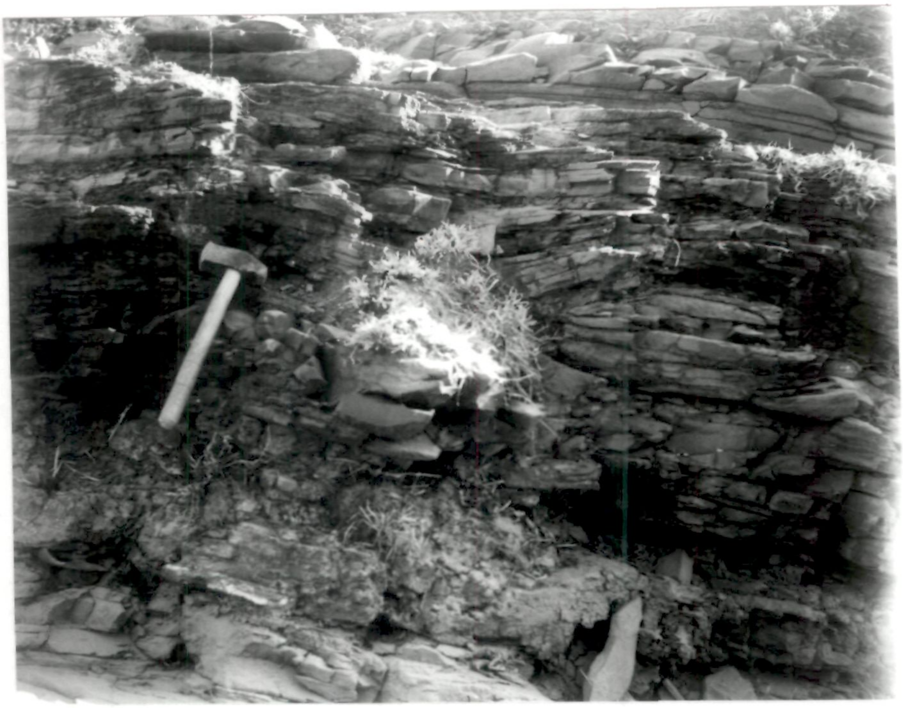

Fig.1

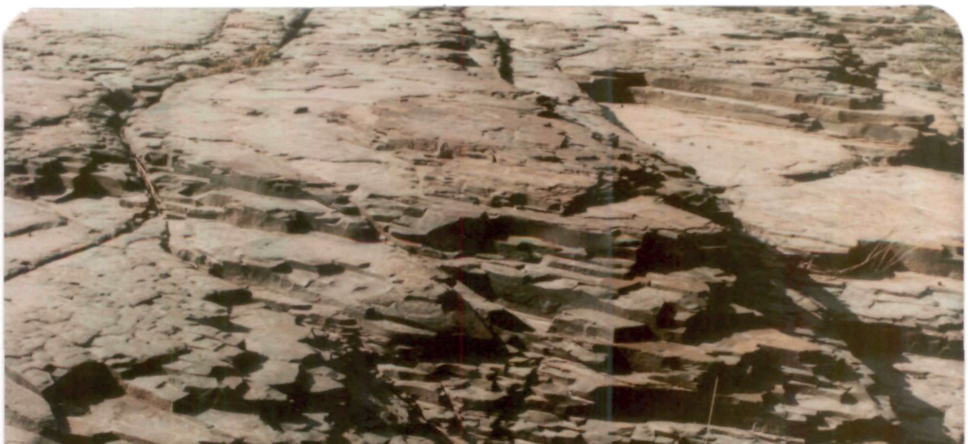

Fig. 2

P L A T E - 13

Fig. 1 Photograph of thinly bedded shale/siltstone (Fsc) facies; Bari Formation.

Fig. 2 Photograph of calcareous shale (Fsc) facies, showing desiccation cracks; Bari Formation. Hammer (30cm) for scale.

beds in the later, are characteristic of Fsc facies. Such fine laminites are analogous to the 'tidal bedding' deposits observed on modern high intertidal flats, whose deposition results from rapidly flowing waters of high suspended mud content (Reineck, 1967). The coarser laminae in these couplets represent low-energy traction deposits, whereas the shales are suspensates that settled out during slack water periods.

The calcareous shale, the main constituent of this lithofacies represent deposition from suspension in a low energy environment of subtidal lagoon as it is suggested by the presence of parallel lamination and general absence of current and wave formed structures (Reinson, 1984; Walker, 1984). However, the presence of mud cracks and flat pebbles at certain levels in the sequence is suggestive of intertidal conditions.

The green coloured shale which abounds in this facies may be due to persistent reducing conditions due to the high water table (Reading, 1978, 1986).

Channel Sandstone facies (Sch). - Small channel sandstone bodies essentially biconvex varying from about 30cm to 2m in width and 20 to 80cm in thickness, occur as isolated or laterally coalescent bodies or are arranged en-echelon (Plate 14, Fig. 1) vertically occur in cross bedded, coarse grained Sawa Sandstone. Internally these bodies may consist of cross-bedding or horizontal bedding or curved bedding (Plate 14, Fig. 2 & Plate 15, Fig. 1). The channel sandstone is fine to medium grained locally coarse grained and greyish white to

PLATE 14

Fig. 1

Fig. 2

P L A T E - 14

Fig. 1 Photograph of channel sandstone facies (Sch), showing biconvex sand body; Sawa Formation. Ball Pen (14 cm) for scale.

Fig. 2 Photograph of channel sandstone facies (Sch), showing curved bedding. The sediments in channel are fine grained than surrounding sediments. Sawa Formation. Ball Pen (14cm) for scale.

PLATE 15

Fig. 1

Fig. 2

P L A T E - 15

Fig. 1 Photograph of channel sandstone facies (Sch), characterised by fine grained sediments; Jiran Formation. Ball Pen (14 cm) for scale.

Fig. 2 Photograph of Ripple laminated sandstone (Sr) facies, characterised by asymmetrical ripples; Jiran Formation. Ball Pen (14cm) for scale.

pinkish white in colour. The orientation of the channel axes, closely coinciding with the strike of cross foresets, is directed towards north, diagonal to the regional palaeoflow direction as inferred from the associated cross-bedded sandstone facies. These features suggesting foreset growth and channel boundaries are sharp (erosional) in sandy areas. Top convexity is due to erosion (Plate 14, Fig. 1). The sediments filled in channel are of both types, different to the surrounding (Plate 14, Fig. 2) and same to the surrounding (Plate 14, Fig. 1 & Plate 15, Fig. 1) sediments.

Interpretation. - The Sch facies is the characteristic feature of intertidal environment (Ginsberg, 1975) where alternating erosion and deposition occur due to rapid changes in current or wave velocity. The channels are filled with sediments which indicate progressive decline in current velocity causing a rather rapid deposition, leading to quick dumping of sediment load (Reineck and Singh, 1980, P.72).

The occurrence of erosional scours, horizontal and trough cross-beds and concave upward lower bounding surfaces of individual channels are evidence of deposition by vertical aggradation (Moody-Stewart, 1966; Campbell, 1976; Collinson, 1978). It appears that the scoured surfaces are produced due to sudden increase in current velocity and subsequently filled in response to the decrease in current velocity (Kumar and Singh, 1978).

Ripple Laminated Sandstone (Sr). - The ripples occurs mainly towards the top of the Jiran Sandstone. The sandstone is fine

PLATE 16

Fig.1

Fig.2

P L A T E - 16

Fig. 1 Photograph of Ripple laminated sandstone facies (Sr), showing symmetrical ripples; Jiran Formation. Ball Pen (14cm) for scale.

Fig. 2 Photograph of Lithofacies A, showing horizontal, wavy and continuous laminae. Note the Palisade structure appears as faint vertical lines in limestone laminae; Bhagwanpura Formation. Hammer (30cm) for scale.

to very fine grained and pink to pinkish brown in colour. The Sr facies occur over the St or Sp facies or interbedded with them and is characterised by the various types of ripples and ripple-laminated sets. Long and round crested asymmetrical ripples (Plate 15, Fig. 2) as well as long crested wave generated symmetrical ripple marks (Plate 16, Fig. 1) are seen at Bamaniya and Saralai. The wave length of symmetrical ripples varies from 1 to 5cm. However, wave length of asymmetrical ripple varies from 2 to 7cm.

Interpretation. - The ripples are the undulations produced as a result of the interaction of current or waves on a noncohesive surface of sediments. Symmetrical ripple marks are formed by oscillatory wave motion (Bagnold, 1946) and the asymmetrical ripple marks are formed by the directional currents but they could also be originated by wave action (Evans, 1941; Kuenan, 1950). Allen (1968) described asymmetrical ripple marks as sinuous ripples having long crest which characterised by a crestline trace that shows more or less smooth waves generally of large 'wave length' compared to amplitude and formed by current. According to Reineck and Singh (1980) asymmetrical ripple marks represent a transition form between low energy straight crested small ripples and higher energy lingoid small ripples.

Rip channel, bar and longshore trough facies of Nearshore environment are characterised by landward or seaward oriented ripples, current ripples and mega ripples. In longshore trough facies of oblique-bar-rip channel system, the longshore currents formed the current ripple oriented normal

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to the shore line. Under high energy conditions longshore currents may generate mega ripples or even upper ~~plane beds~~.

The rip currents are also formed landward, seaward oriented ripple and lunate mega ripples in longshore bar facies of nearshore (Hunter et al. 1979; Davidson Arnott and Green Wood, 1976 P.154; Hunter et al, 1979; Davis, 1985, Emisele, 1992). Asymmetrical ripples are also formed by oscillatory origin in the foreshore zone (Evans, 1941; Davis, 1985).

The surge and backwash of the swash zone will generate ripples only if the waves are gentle. Rounded crested symmetrical ripples are formed in rather deep water while strongly peaked ripples are more common in very shallow near emergent conditions (Collinson and Thompson, 1982).

Landward and seaward oriented mega ripples may be formed in channel margin, linear bars, swash bars and flood and ebb tidal delta by the migration of tidal currents or waves (Hubbard and Barwis, 1976; Hayes, 1980; Reinson, 1984). The long crested symmetrical and asymmetrical ripples are formed by tidal currents in the lower and middle part of intertidal zone (Klein, 1970b,Mackenzie, 1975) (Plate 15, Fig. 2 & Plate 16, Fig. 1). The asymmetric ripples suggest tractional current tidal flow under the lower flow regime (Klein, 1970b, 1985).

Herringbone Crossbedded Sandstone (S-hb). - In this facies, cross-bedding formed in coset with each set show opposite directions to each other. Mostly large scale trough type cross-bedding is seen at places but planar type cross-bedding occurs locally.

The planar cross-beds occur in coset, each set showing opposite direction to each other. In vertical section, parallel to current direction, the foresets are sharply truncated at top and bottom although some foresets have gently tangential bases.

The herringbone cross-bedded sandstone is fine to medium grained and locally coarse grained and whitish grey, pinkish white, yellowish to dark reddish in colour. Each cross-bedded set may vary in thickness from 10cm to 75cm. Thickness of this facies ranges from 50cm to 2.5m and can be traced for a short distance. The herringbone cross-bedded facies is mostly interbedded with St or Sp facies. This facies is well developed at Palri, Angoria and Dhani in Sawa Sandstone (Fig.6), Sajanpura and Barvara in Khori-Malan Sandstone (Fig.7), Bamaniya and Bari in Jiran Sandstone (Fig.8).

Interpretation. - Herringbone cross-bedding is formed by
1978 reversal tidal currents (Klein, 1971, 1985; Reading/, Leekie and Walker, 1982; Reinson, 1984, P.127; Davis, 1985). Reading (1978, P.235) and Reineck and Singh (1980, P.99) interprete that the herringbone structure in sandstone as a diagnostic feature of tidal currents. Clifton and Thompson (1978) attributed these structures to intertidal and shallow subtidal environments. Herringbone cross-bedding is formed by alternate migration of flood (landward) and ebb (seaward) oriented cuspate mega ripples or excellent indicator of reversing or bidirectional flow in estuaries (Boothroyd, 1985).

Lithofacies A. - This facies characterized through out by a pink colour, mainly consist of laminated micritic limestone which is very thin bedded to thin bedded (1-4cm thick beds) in the lower part and laminated in the upper part. The limestone laminae is horizontal, wavy, continuous and range in thickness from 1mm to 1cm (Plate 16, Fig. 2). This facies range in thickness from 25cm to 4m and can be traced laterally for a long distance. The limestone laminae often show vertical fluting which bear a strong resemblance to the palisade structure described by Davies (1970 a, P.186) from recent algal mat sediments. Davis (1970 a) believed that, this structure is formed by vertical algal filaments growing upward through sediment laminae and it marks the position of a zone of active filament. Lithofacies A is well developed in Bhagwanpura limestone at Unthail.

Interpretation. - Hardie (1977) described that flat lamination, undulating lamination, thin beds, stromatolite, mud cracks, sheet cracks, flat pebble gravels and intra clastic sands are diagenetic features found in carbonate deposits of tidal flat environment. Black (1933) first pointed out the major role played by mats of filamentous blue green algal in producing distinctive lamination on the tidal flats. Shinn et al. (1965, 1969) found that layering is confined to sediments in the upper intertidal and supratidal zones.

Hardie and Ginsburg (1977) distinguish three major kinds of layering : (1) Flat mm lamination on natural levees of tidal creeks and on beach ridges (2) mm lamination with palisade structure in cemented crusts that occur just above the normal high water mark. (3) thick lamination and Cm scale thin beds in the fresh water algal marsh. Davies (1970 a) is also described the layering is the characteristic of carbonate rocks in intertidal zone. Layering is the most obvious structure in the tidal zone of modern carbonate environments which give an association of flat and undulating lamination that closely resembles that of many ancient carbonates (Hardie & Ginsburg, 1977; Zamarreno, 1975). Thus it is interpreted that lithofacies A may be deposited in tidal flat or tidal zone.

Lithofacies B. - This facies is characterized by 20cm to 1m thick beds and lithologically comprised of blackish to yellowish brown micritic limestone which is siliceous and dolomitic in composition, hard and crystalline in nature. The dolomite bed appear rust-coloured on weathered surfaces and occur as delicate sharp ridges. They are wavy and discontinuous and extend laterally for a long distance. Red, hard crystalline dolomite appear as massive but on weathered surfaces show faint traces of parallel lamination.

Lithofacies B is characterised by well developed intraformational breccia, ripple marks and desiccation cracks (Plate 17, Fig. 1) and locally contain cross lamination, Symmetrical, asymmetrical and interference ripple marks are recorded in this facies. They are mostly confined to yellowish brown silicious and dolomitic limestone. Of the three types, the symmetrical type ripples is more common (Plate 17, Fig.1). The intraformational breccia is present locally in the limestone units. It consists of angular, subrounded and Platy fragments of limestone measuring from less than a centimeter to as much as 8cm. The intraformational breccia or conglomerate is a rudaceous deposit formed by penecontemporaneous fragmentation and redeposition of the carbonate stratum. Its occurrence near marginal shallower parts of the basin of carbonate deposition would indicate the prevalence of relatively high energy conditions resulting in the penecontemporaneous fragmentation and redeposition of the semi-consolidated carbonate stratum.

The desiccation cracks are mostly restricated to the argillaceous units through incipient cracks, are noticed locally in the yellowish brown and pinkish yellow limestone units. The cracks are generally filled with calcareous matter. This facies a few centimeter to few meter thick and can be traced laterally for a long distance in Bhagwanpura Limestone Formation. The good exposures of the facies are seen at Bhalundi and Palri.

Interpretation. - The intraformational breccia, desiccation cracks, ripple are the diagnostic feature of tidal flat or intertidal environment. (Ginsburg, 1975; Hardie, 1977; Hardie and Ginsburg, 1977; Minero. 1991; Wright, 1992).

Lithofacies C. - Lithofacies C characterised throughout the area by a black or yellowish brown stromatolitic limestone. The limestone is very hard and compact and siliceous and dolomitic in composition. Stromatolites are the fossilised remains of the laminated, columnar (Plate 17, Fig. 2) and

PLATE 17

Fig.1

Fig. 2

P L A T E - 17

Fig. 1 Photograph of Lithofacies B, showing ripple marks and intraformational breccia in Bhagwanpura Limestone Formation.

Fig. 2 Photograph of Lithofacies C, showing stromatolite structure in Bhagwanpura Limestone Formation.

nodular structure (Plate 1, Fig. 2) in carbonate rocks resulting by the trapping and binding of material by blue green algae and bacteria. The stromatolites generally occur as recemented fragments within limestone or as cracked ripples, the fracturing being caused by desiccation. The stromatolites develops in restricted parts of the basin and do not show any regularity in their pattern of distribution. The dolomite bed appear rust coloured on weathered surfaces and occur as sharp ridges. Red, hard and crystalline dolomite appear as massive but on weathered surfaces show faint traces of parallel lamination. Gebelein and Hoffman (1971) have suggested that magnesium concentration in algal filaments provides a source of magnesium for the dolomite in millimeter - laminated limestone- dolomite cryptalgal laminites. Dolomite rich laminations of this facies contain rhombs are often stained red, brown or yellow with iron oxides. This facies a few centimeter to 2.5m thick and can be traced laterally for a very long distance. Good exposures of columnar and ripple like assemblages of algal structures are recorded at Bhagwanpura, Palri and Bhalundi in Bhagwanpura limestone.

Interpretation. - According to Logan and others (1964), the ripple like stromatolites is being suggestive of protected intertidal mud flat where as columnar stromatolites exposed intertidal conditions. The brownish yellow colour of the stromatolitic limestone and presence of detrital clastic sediments are indicative respectively of deposition in an oxidising environment and the nearness of depositional site to land. The occurrence of stromatolite indicates fluctuating basin condition of deposition. Kendall and Skipwith (1968) and Davies (1970 a, b) interpreted that algal mats develop typically near the upper edge of the intertidal zone and in the transitional zone on to the supratidal flats. The distinctive columnar stromatolites , conophyton may be exclusively subaqueous form while the poorly laminated conophyton like columns may grow in foreshore basins of water 10 to 100 meter deep (Banerjee, 1980). Stromatolites deposits accumulated in a long persisting subtidal, intertidal and supratidal environment reflect very stable tectonic and environmental conditions (Song and Gao, 1985; Einsele, 1992).

Lithofacies D. - Lithofacies D occur in the lower part of Nimbahera Limestone and consist of pinkish to purplish argillaceous limestone which are thin to very thin bedded (Plate 18, Fig. 1). The limestone is massive, hard, compact and jointed and micritic in composition. This facies generally grades into underlying Bari Formation through calcareous shale. Thin shale parting occur within the limestone at places. Lithofacies D is range in thickness from 1 to 12m. Each limestone bed, is horizontal, wavy and continuous and 1 to 6 cm. thick and extend laterally for a long distance. This facies is well developed at Tatarmala and Binota in Nimbahera Limestone.

Interpretation. - Micrite forms in areas of ineffective winnowing and calm waters of low energy like protected lagoon (Folk, 1980). The micritic composition of the limestone and absence of strong wave action or subaerial exposures may imply

PLATE 18

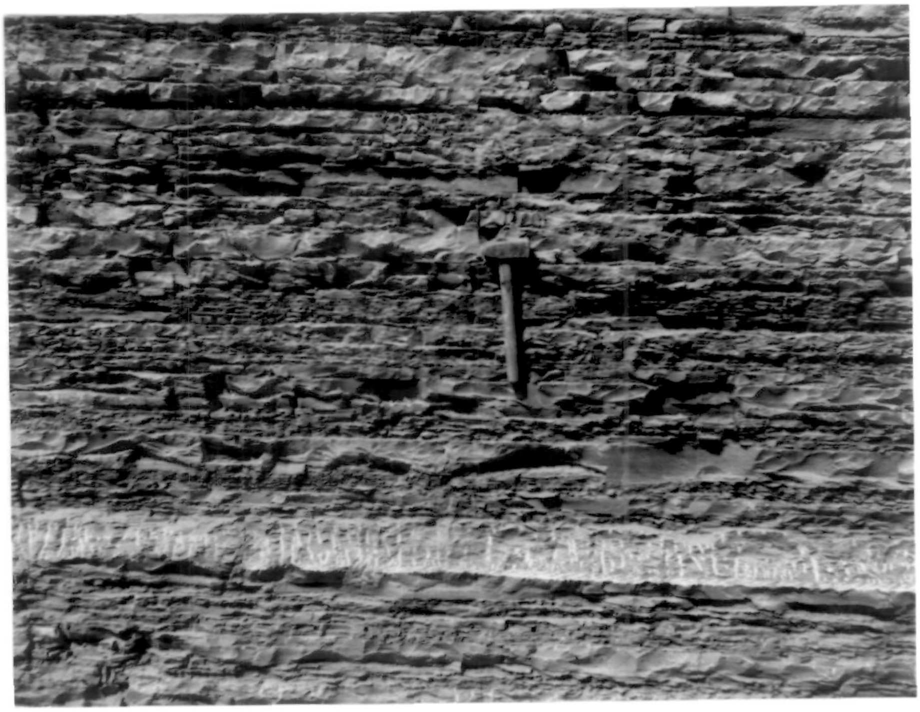

Fig. 1

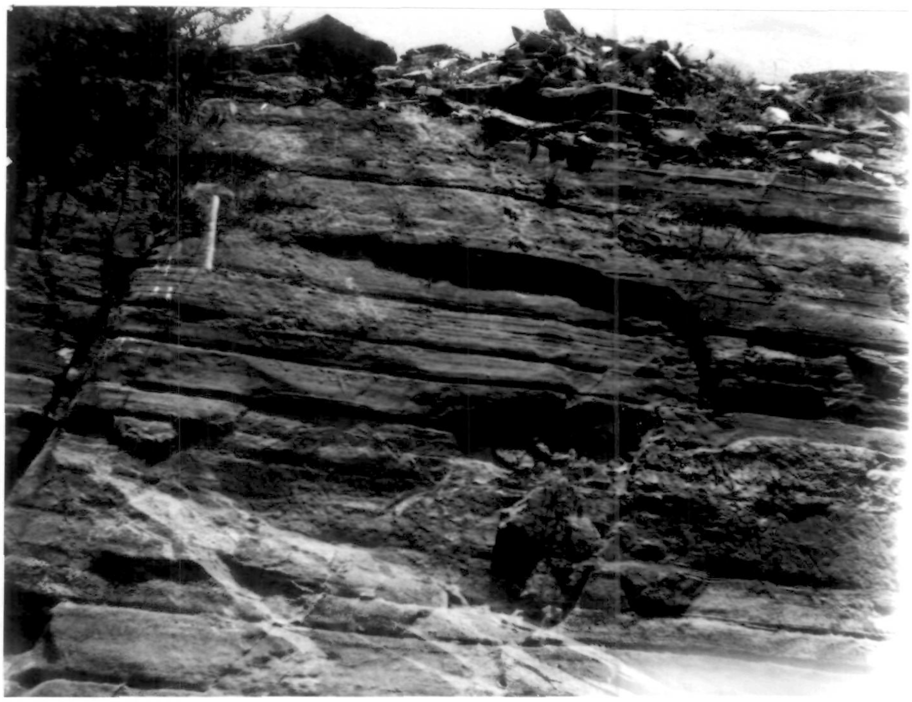

Fig. 2

P L A T E - 18

Fig. 1 Photograph of Lithofacies D, showing thin to very thin bedded argillaceous limestone; Nimbahera Limestone Formation. Hammer (30cm) for scale.

Fig. 2 Photograph of Lithofacies E, showing horizontal and thick-bedded limestone; Nimbahera Limestone Formation. Hammer (30cm) for scale.

that lithofacies D might have been deposited in a low energy subtidal lagoonal environement (Minero, 1991).

Lithofacies E. - This facies is characterised throughout by pale bluish grey to dark grey colour micritic and non-stromatolitic limestone which are thin to thick bedded, occur in the middle to upper part of Nimbahera Limestone. This facies is mostly horizontal bedded (Plate 18, Fig. 2). The limestone bed ranges in thickness from 20cm to over a meter. Lithofacies E range in thickness from 2 to 12m and can be traced laterally for long distance depending upon length and depth of quarries or outcrops. Lithofacies E lies directly over the facies (D) with gradational contact. This facies is well developed at Binota, Mandla Charan and Sawa.

Interpretation. - Lithofacies E is thick-bedded, massive and entirely composed of micrite may suggests a low energy environment of deposition. Dark grey or black colour (Friedman and Sanders, 1978, P. 128) of micritic limestone is to represent reducing depositional environments. Non-stromatolitic limestone is therefore interpreted to have deposited under reducing conditions from suspension in deep sub-tidal region of a carbonate tidal flat. The deep condition of the basin, presence of thick, homogeneous, horizontal beds of limestone further support such a contention. Abundance of micrite and absence of terrigeneous admixture and high energy sedimentary structure such as ripples marks, cross bedding, intraformational breccia, stromatolites, scour and fill structure may suggests that Lithofacies E may be deposited in the shallow subtidal lagoon environment (Soderman and Carozzi, 1963; Jindrich, 1969; Blatt et al, 1972; Minero, 1991).

C H A P T E R III

T E X T U R E

GRAIN SIZE ANALYSIS

General Remarks. - Grain size is an important tool to understand the sedimentary processes and environments of deposition. But the difficulty arises when the grain size distribution shows the similar parameters of different environments of deposition. Even then the grain size distributions can be used to understand the sedimentary processes and environments of deposition. During last few decades years, the environment of deposition has been determined on the basis of grain size distribution (Folk and Ward, 1957; Mason and Folk, 1958; Duane, 1964; Friedman, 1961, 1967, 1979; Friedman and Johnson, 1982; and Moiola and Weiser, 1968). These workers have used the statistical measures such as Mean size, Standard deviation, Skewness and Kurtosis to seperate beach, dune, aeolian and fluvial environments. This approach has been moderately successful in modern sediments but less successful in interpreting the genesis of ancient sediments.

Doeglas (1946) observed that (1) grain size distribution are mixtures of two or more populations and that (2) these populations were produced by varying transport conditions. Inman (1949) recognized three fundamental modes of transport, surface creep, saltation and suspension on the basis of shape and size of the particles. These processes were applied by

Moss (1962, 1963) using the shape and size of the grain and distinguished subpopulations.

Statistical parameters such as Skewness and Kurtosis were referred to as indicators of selective action of transporting agent by Krumbein and Pettijohn (1938). Folk and Ward (1957) suggested that sands deposited near the source are characteristically leptokurtic and positive skewed. The leptokurtic nature indicates river sediments whereas mesokurtic nature is charateristic of beach and intertidal sediments. Mason and Folk (1958) made a comparative textural studies of Recent sands of beach, dune and aeolian environments. These studies indicated that beach sand are normal or negative skewed and leptokurtic, dune sands have positive skewness and are mesokurtic and aeolian sands are positively skewed and leptokurtic. Friedman (1961) suggested that beach sands generally have negative skewness, but both dune and river sands usually have positive skewness. Duane (1964) demonstrated that the sands of the littoral, beach and tidal inlet environments have negative skewness as a result of winnowing action of waves and tidal currents. In sheltered quiet water areas and in deeper water, where bottom currents or wave base surge are not effective, the sands have positive skewness. Sediments show local variation in the sign of skewness in areas of fluctuating energy.

To study the textural parameters of the Lower Vindhyan sediments, the four major sandstone formations of the area, viz the Khardeola, Sawa, Khori-Malan and Jiran Sandstone and one member, Bhagwanpura Sandstone were selected. As these sandstone are very hard and compact and cemented with silica which has grown in optical continuity with the detrital grains. Therefore only recourse to study the textural and compositional characters was in thin sections.

Methodology. - The samples collected during the field work from all sandstone formations were studied for textural attributes. 57 thin sections (12 from Khardeola, 2 from Bhagwanpura, 19 from Sawa, 11 each from Khori-Malan and Jiran Sandstones) were selected for grain size analysis.

The apparent long axis of 200 grains which could be clearly distinguished excluding the overgrowths, were measured per thin section with the help of micrometer eyepiece. The technique of point counting as described by Chayes (1949) was employed for a uniform coverage of a thin section for the grain size analysis. The data were grouped into size classes with the intervals of half phi (0.5ϕ) classes (Appendix - I). From the number percentage data the cumulative curves were drawn on the graph paper described and developed by Friedman (1958) to determine the sieve size equivalents of thin section data (Fig.9, 10 & 11). The cumulative curves (Fig. 12, 13 & 14) are also plotted on the basis of cumulative frequency drawn on probability graph paper following Visher (1969). From these curves the phi (ϕ) values for 5%, 16%, 25%, 50%, 75%, 84% and 95% were determined (Table - 2).

From these data, the graphic measure of the grain size properties like graphic mean (Mz), inclusive graphic standard deviation (σI), inclusive graphic skewness (SKi) and Kurtosis were calculated (Table - 3) by using the formula given by Folk

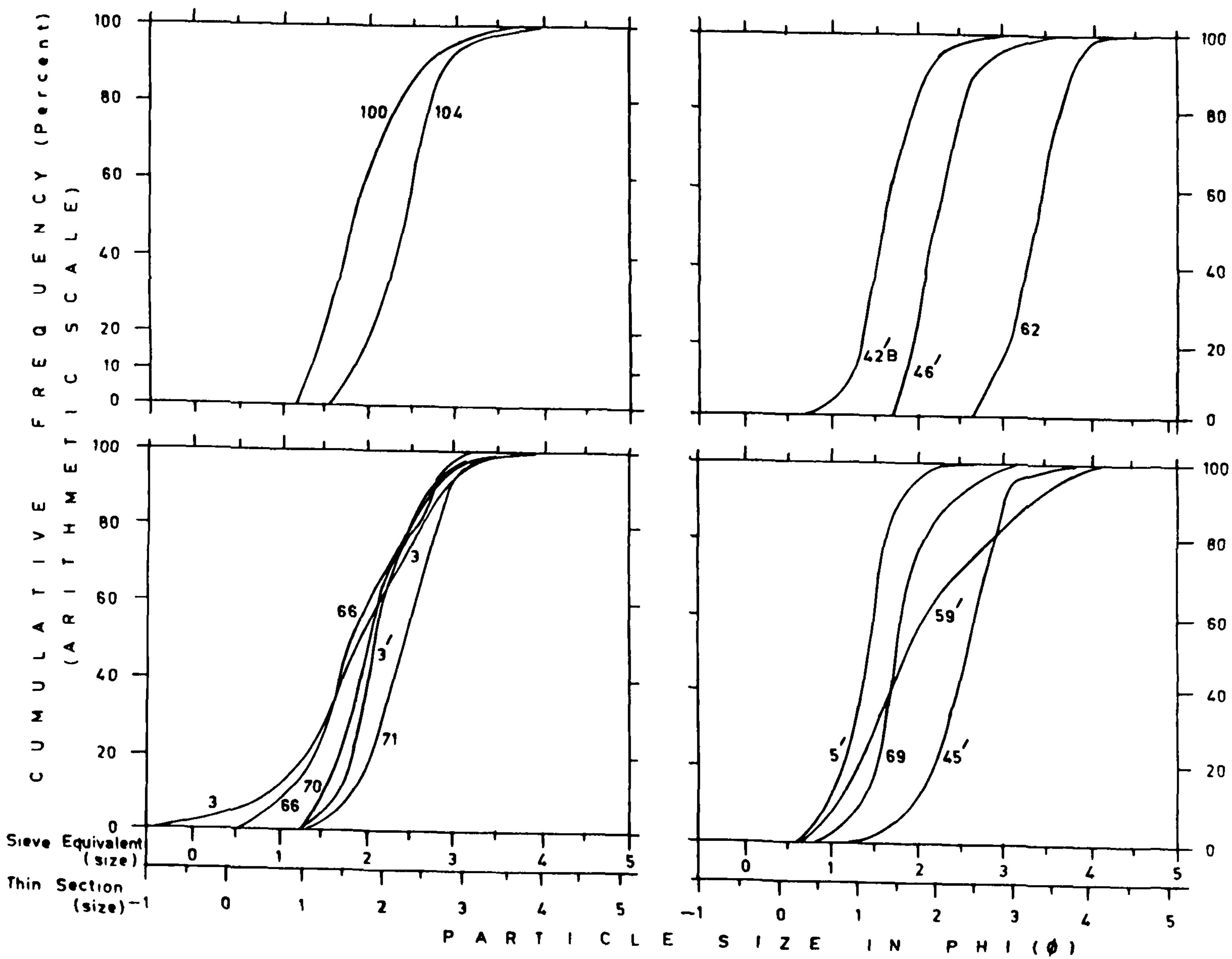

Fig. 9 Cumulative frequency curves showing Grain size distribution of Khardeola and Bhagwanpura Sandstones (after Friedman, 1958)

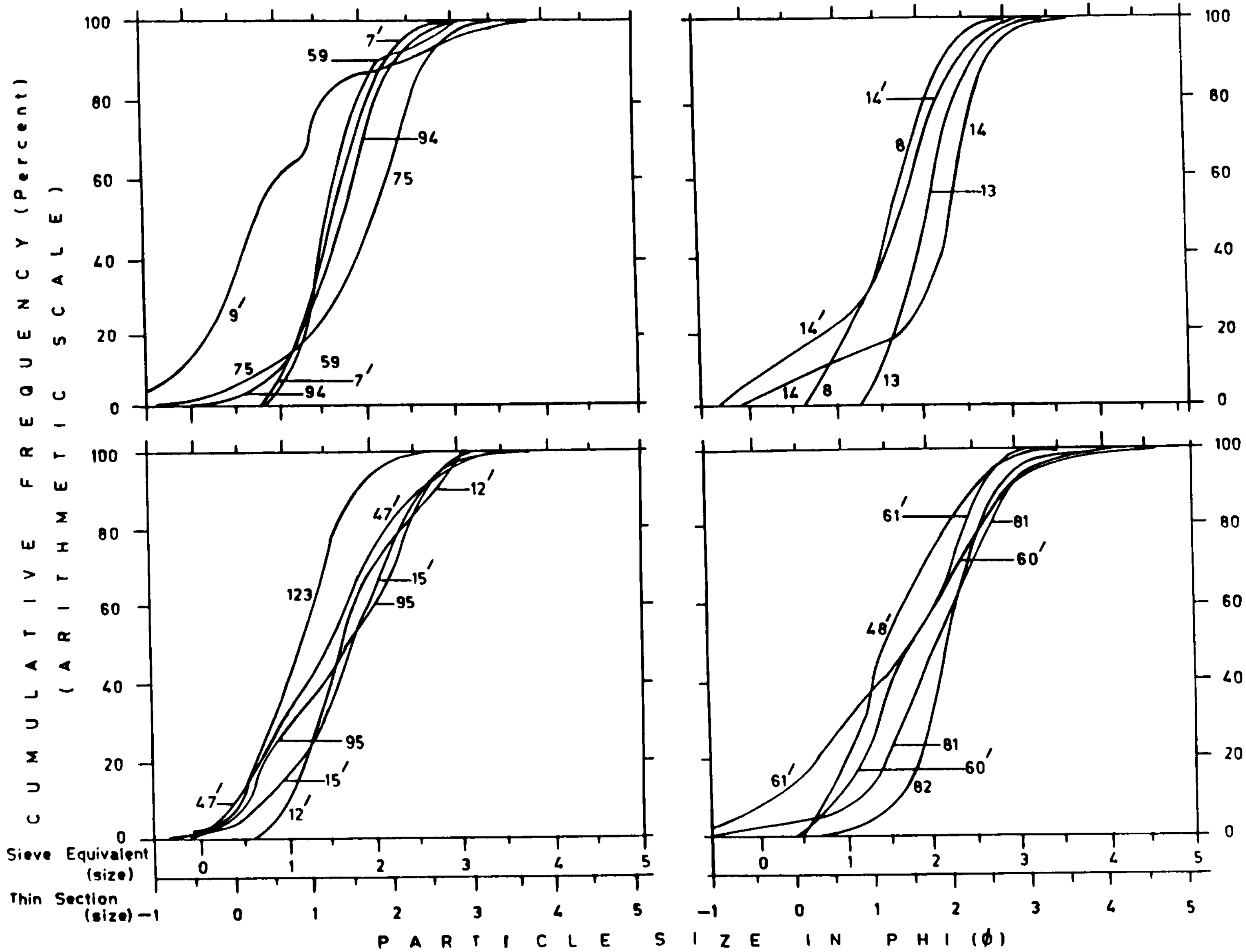

Fig. 10 Cumulative frequency curves showing Grain size distribution of Sawa Sandstone (after Friedman, 1958).

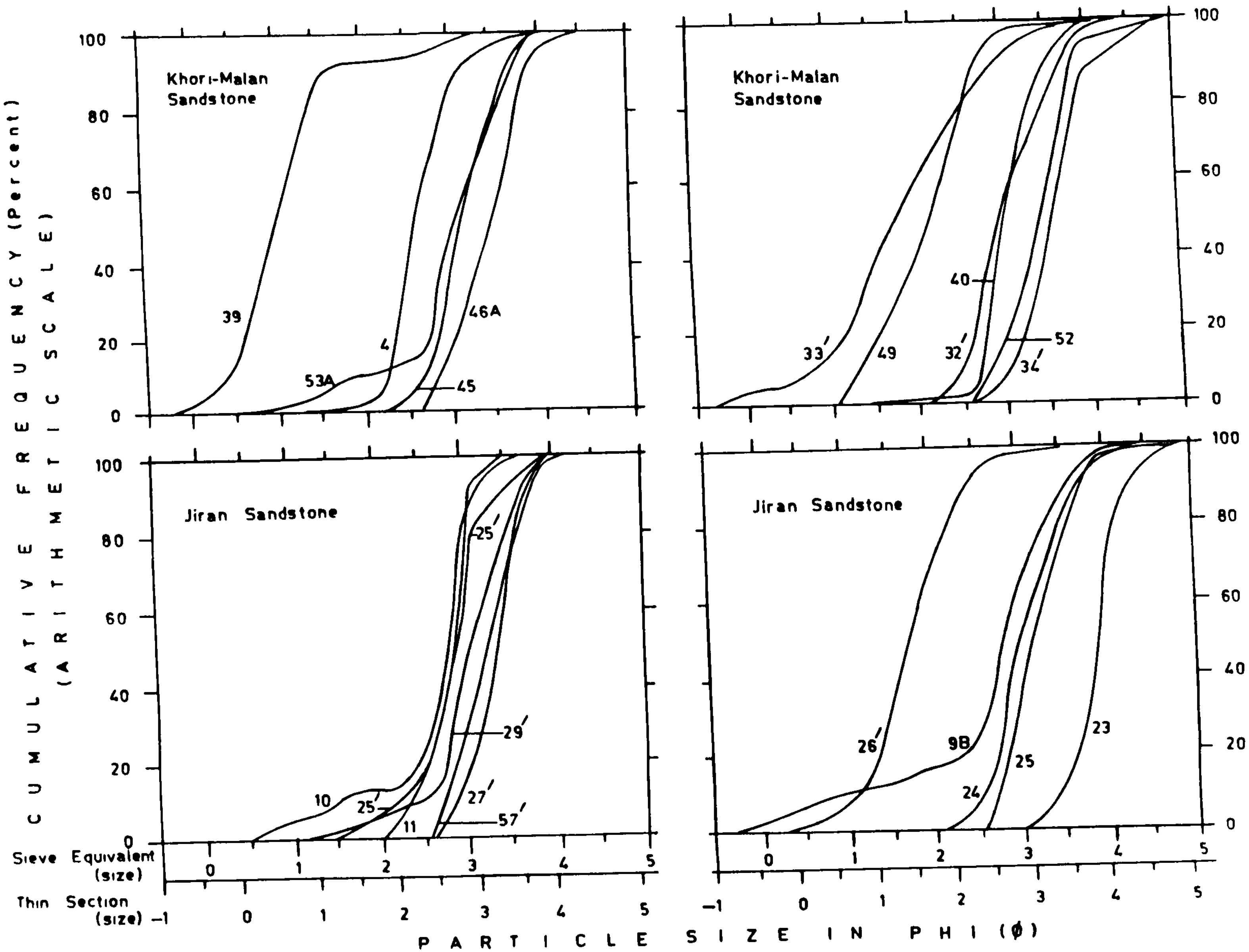

Fig. 11 Cumulative frequency curves showing Grain size distribution of Khori-Malan and Jiran Sandstones (after Friedman, 1958)

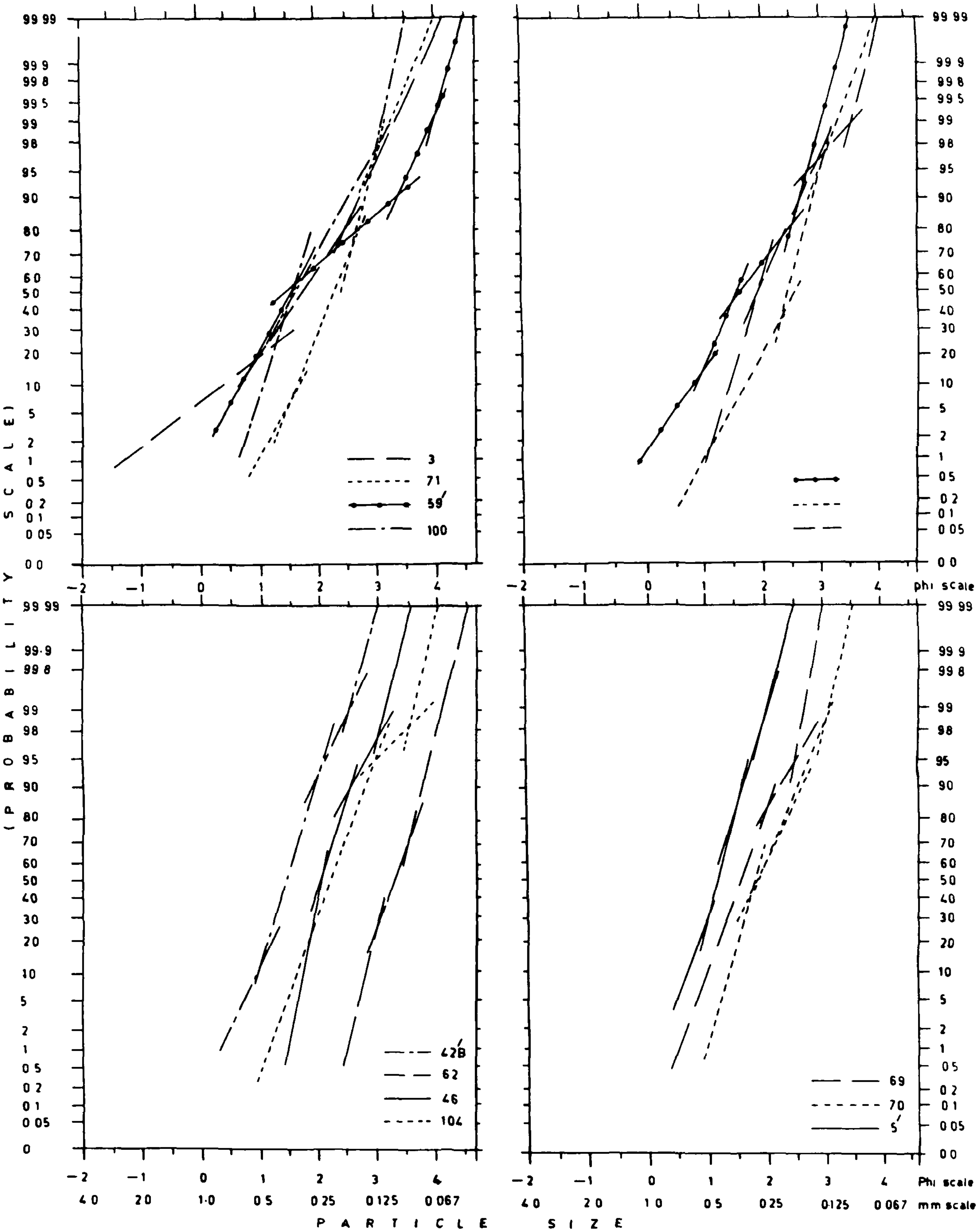

Fig 12 Cumulative frequency curves drawn on probability paper showing Grain size distribution of Khardeola and Bhagwanpura Sandstones (after Visher, 1969)

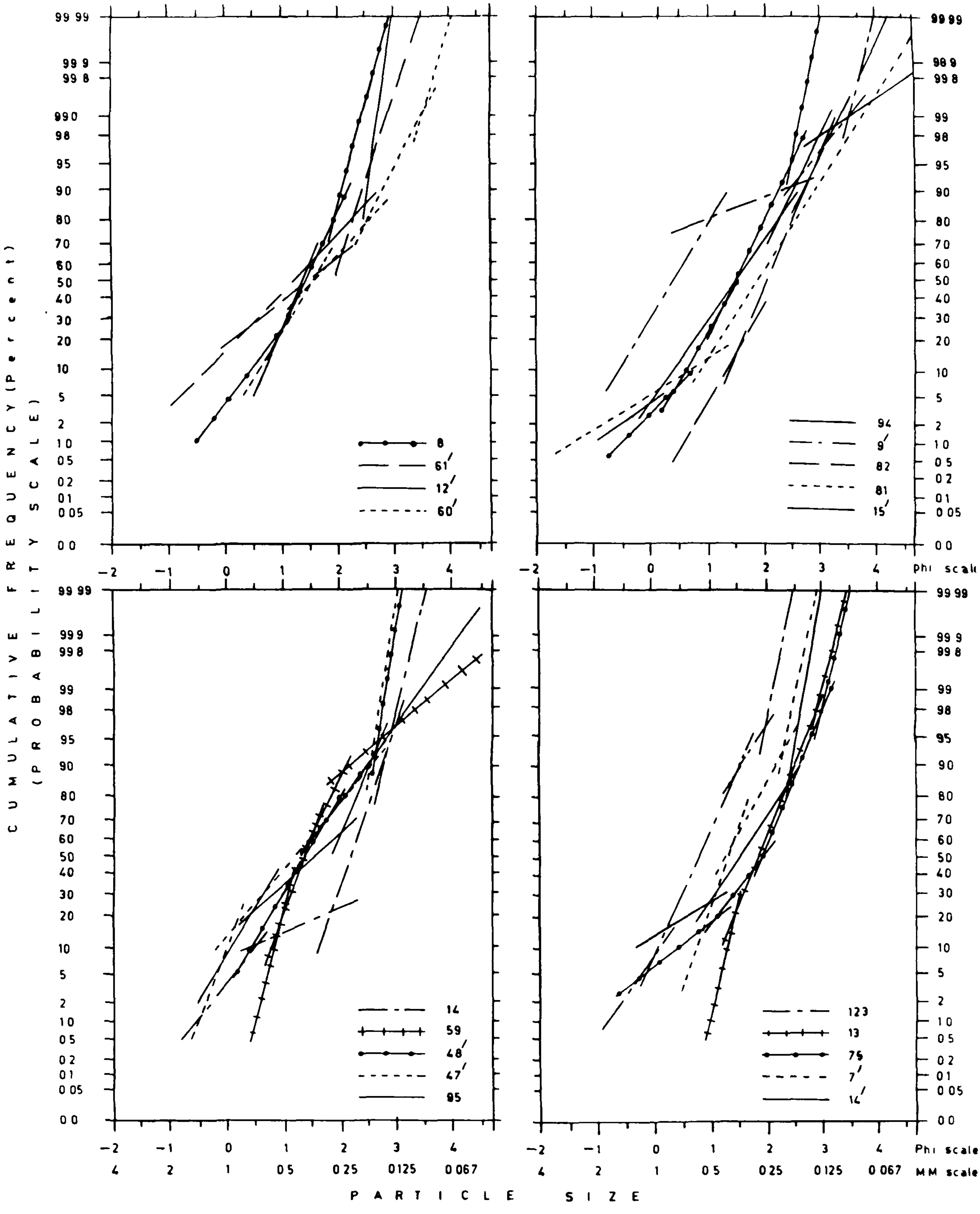

Fig. 13 Cumulative frequency curves drawn on probability paper showing Grain size distribution of Sawa Sandstone (after Visher, 1969).

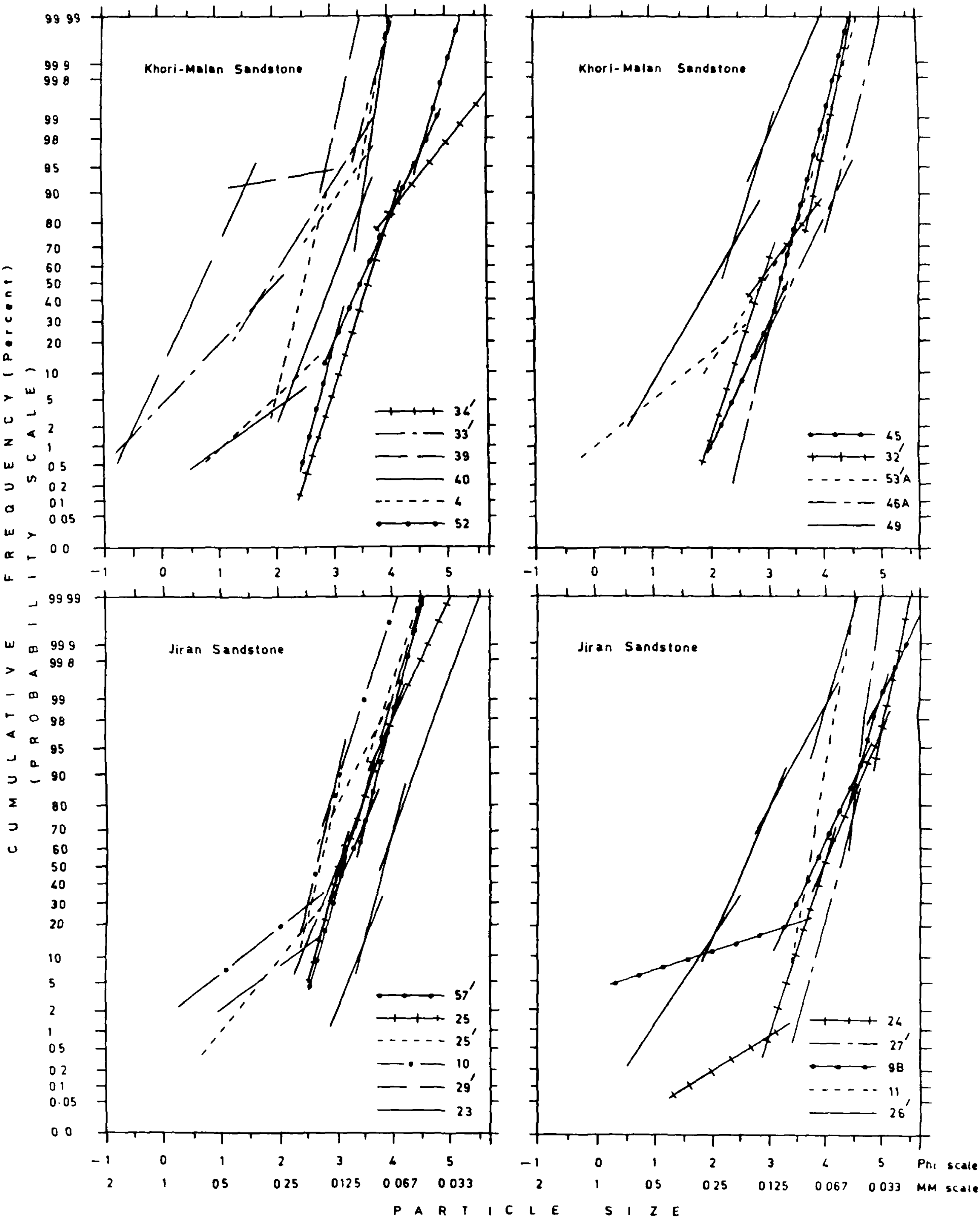

Fig. 14 Cumulative frequency curves drawn on probability paper showing Grain size distribution of Khori-Malan and Jiran Sandstones (after Visher, 1969).

Table - 2 Grain size Frequency Percentile in phi (Ø) units of Lower Vindhyan Sandstone of Bhadesar - Nimbahera area, Rajasthan.

S. No.	Sample Number	Locality	Ø 5	Ø 16	Ø 25	Ø 50	Ø 75	Ø 84	Ø 95
				KHARDEOLA SANDSTONE					
1	66	Ladder	0.85	1.33	1.50	1.82	2.35	2.70	2.90
2	3'	Sand	1.50	1.77	1.88	2.10	2.41	2.60	3.00
3	5'	Sand	0.80	1.10	1.25	1.45	1.60	1.70	2.00
4	69	Sand	1.10	1.45	1.58	1.75	1.95	2.17	2.70
5	70	Sand	1.40	1.65	1.77	2.03	2.37	2.60	2.95
6	71	Sand	1.70	1.96	2.13	2.47	2.73	2.90	3.07
7	59'	Sand	0.85	1.23	1.40	1.87	2.70	3.14	3.66
8	45'	Unthail	1.65	2.10	2.26	2.56	2.85	2.96	3.14
9	46'	Unthail	1.80	1.90	2.05	2.20	2.50	2.60	2.96
10	62	Unthail	2.75	2.97	3.15	3.40	3.63	3.80	3.94
11	42'B	Ratanpur	1.10	1.35	1.40	1.60	1.90	2.05	2.25
12	3	Ratanpur	0.40	1.20	1.45	1.90	2.55	2.74	3.14
				BHAGWANPURA SANDSTONE					
13	100	Minana	1.29	1.44	1.55	1.83	2.25	2.50	2.95
14	104	Minana	1.70	1.92	2.10	2.44	2.65	2.80	3.15

S. No.	Sample Number	Locality	Ø 5	Ø 16	Ø 25	Ø 50	Ø 75	Ø 84	Ø 95
				SAWA SANDSTONE					
15	60'	Dhani	0.73	1.14	1.34	1.80	2.52	2.78	3.20
16	61'	Dhani	-0.23	0.50	0.85	1.78	2.38	2.55	2.80
17	12'	Angoria	0.85	1.16	1.30	1.63	2.17	2.55	2.93
18	14'	Angoria	-0.05	0.70	1.27	1.75	2.25	2.45	2.75
19	15'	Angoria	0.50	0.85	1.26	1.77	2.30	2.55	2.86
20	81	Kesarpura	0.73	1.40	1.60	2.10	2.63	2.85	3.20
21	82	Kesarpura	1.40	1.77	1.92	2.22	2.55	2.70	3.04
22	7'	West of Shergarh	0.85	1.20	1.35	1.56	1.95	2.15	2.45
23	9'	West of Shergarh	-0.60	0.05	0.30	0.80	1.50	1.70	3.05
24	75	Shergarh	0.50	1.20	1.52	2.10	2.50	2.65	2.90
25	94	Palri	0.75	1.15	1.33	1.75	2.10	2.20	2.65
26	95	Palri	0.40	0.66	0.90	1.73	2.35	2.50	2.90
27	123	South of Palri	0.30	0.55	0.75	1.20	1.55	1.67	2.07
28	47'	Unthail Khera	0.25	0.58	0.83	1.53	2.05	2.35	2.86
29	48'	Unthail Khera	0.65	0.90	1.15	1.50	2.10	2.44	2.80
30	59	Unthail	0.95	1.20	1.30	1.60	1.88	2.05	2.70

S. No.	Sample Number	Locality	Ø 5	Ø 16	Ø 25	Ø 50	Ø 75	Ø 84	Ø 95
31	8	Bhagwanpura	0.75	1.05	1.33	1.65	2.05	2.20	2.50
32	13	Binota	1.42	1.62	1.80	2.06	2.33	2.54	2.88
33	14	Binota	0.30	1.43	1.97	2.38	2.60	2.73	3.00
				K H O R I - M A L A N S A N D S T O N E					
34	4	Barvara	2.15	2.34	2.42	2.65	2.95	3.05	3.50
35	32'	Sajanpura	2.40	2.67	2.75	3.06	3.53	3.70	3.94
36	33'	Sajanpura	0.40	1.50	1.40	1.84	2.55	2.84	3.35
37	34'	Sajanpura	3.00	3.23	3.38	3.66	3.90	3.97	4.50
38	39	East of Lakshimpura	0.25	0.55	0.70	1.00	1.35	1.50	2.80
39	40	East of Lakshimpura	2.70	2.80	2.90	3.10	3.35	3.50	3.85
40	45	Tatarmala	2.55	2.80	2.92	3.17	3.54	3.65	3.87
41	53'A	Tatarmala	1.50	2.67	2.80	3.10	3.55	3.70	3.90
42	49	Khorip	1.25	1.56	1.75	2.22	2.60	2.74	2.98
43	52	Khorip	2.76	3.00	3.20	3.50	3.80	3.90	4.06
44	46A	Tatarmala	2.75	2.96	3.16	3.53	3.80	3.90	4.06

S. No.	Sample Number	Locality	Ø 5	Ø 16	Ø 25	Ø 50	Ø 75	Ø 84	Ø 95
				JIRAN SANDSTONE					
45	9B	Bari	0.40	1.90	2.50	2.85	3.23	3.45	3.80
46	10	Makhanpura	1.10	2.30	2.57	2.80	2.97	3.06	3.35
47	11	Makhanpura	2.20	2.50	2.65	2.92	3.05	3.10	3.26
48	25'	Nersa Kheri	1.86	2.44	2.65	2.92	3.10	3.28	3.70
49	27'	Sarali	2.73	2.97	3.14	3.37	3.55	3.65	3.90
50	26'	Marjivi	0.85	1.30	1.44	1.75	2.10	2.30	2.60
51	23	Bamaniya	3.30	3.60	3.74	3.92	4.04	4.20	4.47
52	24	Bamaniya	2.40	2.70	2.77	3.06	3.43	3.60	3.90
53	25	Bamaniya	2.65	2.83	2.94	3.20	3.50	3.60	3.90
54	57'	Sigri	2.67	2.83	2.97	3.30	3.60	3.73	3.92
55	29'	South of Khera	1.90	2.70	2.85	3.10	3.45	3.56	3.85

Table - 3 Statistical Parameters of Grain size distribution of Lower Vindhyan Sandstone of Bhadesar - Nimbahera area, Southeastern Rajasthan. (Mz = Graphic Mean, $\sigma 1$ = Inclusive graphic standard deviation, SK_1 = Inclusive graphic skewness, KG = Graphic Kurtosis)

S. No.	Sample Number	Graphic Mean (Mz) ϕ		Sorting ($\sigma 1$) ϕ		Skewness (SK_1)		Kurtosis (KG)	
				KHARDEOLA SANDSTONE					
1	66	1.95	Medium	0.65	Moderately Well	0.17	Fine skewed	0.99	Mesokurtic
2	3'	2.15	Fine	0.43	Well	0.20	Fine skewed	1.16	Leptokurtic
3	5'	1.42	Medium	0.33	Very Well	-0.12	Coarse skewed	1.41	Leptokurtic
4	69	1.79	Medium	0.42	Well	0.17	Fine skewed	1.78	Very Leptokurtic
5	70	2.1	Fine	0.47	Well	0.19	Fine skewed	1.06	Mesokurtic
6	71	2.44	Fine	0.44	Well	-0.10	Near symmetrical	0.93	Mesokurtic
7	59'	2.08	Fine	0.90	Moderately	0.30	Fine skewed	0.89	Platykurtic
8	45'	2.54	Fine	0.45	Well	-0.14	Coarse skewed	1.03	Mesokurtic
9	46'	2.23	Fine	0.3507	Well	0.22	Fine skewed	1.05	Mesokurtic
10	62	3.39	Very Fine	0.39	Well	-0.06	Near symmetrical	1.01	Mesokurtic
11	42'B	1.66	Medium	0.349	Very Well	0.21	Fine skewed	0.94	Mesokurtic
12	3	1.94	Medium	0.80	Moderately	-0.002	Near symmetrical	1.02	Mesokurtic
				BHAGWANPURA SANDSTONE					
13	100	1.92	Medium	0.51	Moderately Well	0.31	Strongly fine skewed	0.97	Mesokurtic
14	104	2.38	Fine	0.44	Well	-0.10	Near symmetrical	1.08	Mesokurtic
				SAWA SANDSTONE					
15	60'	1.91	Medium	0.78	Moderately	0.16	Fine skewed	0.86	Platykurtic
16	61'	1.61	Medium	0.97	Moderately	-0.29	Coarse skewed	0.81	Platykurtic

S. No.	Sample Number	Graphic Mean (Mz) ϕ		Sorting (σ1) ϕ		Skewness (SK1)		Kurtosis (KG)	
17	12'	1.78	Medium	0.67	Moderately Well	0.29	Fine skewed	0.98	Mesokurtic
18	14'	1.63	Medium	0.86	Moderately	-0.24	Coarse skewed	1.17	Leptokurtic
19	15'	1.72	Medium	0.79	Moderately	-0.08	Near symmetrical	0.93	Mesokurtic
20	81	2.11	Fine	0.73	Moderately	-0.04	Near symmetrical	0.98	Mesokurtic
21	82	2.23	Fine	0.48	Well	0.016	Near symmetrical	1.06	Mesokurtic
22	7'	1.63	Medium	0.48	Well	0.18	Fine skewed	1.09	Mesokurtic
23	9'	0.85	Coarse	0.96	Moderately	0.16	Fine skewed	1.24	Leptokurtic
24	75	1.98	Medium	0.72	Moderately	-0.29	Coarse skewed	1.00	Mesokurtic
25	94	1.70	Medium	0.55	Moderately Well	-0.10	Near symmetrical	1.01	Mesokurtic
26	95	1.63	Medium	0.79	Moderately	-0.11	Coarse skewed	0.71	Platykurtic
27	123	1.14	Medium	0.55	Moderately Well	-0.08	Near symmetrical	0.91	Mesokurtic
28	47'	1.49	Medium	0.84	Moderately	-0.03	Near symmetrical	0.88	Platykurtic
29	48'	1.61	Medium	0.71	Moderately	0.21	Fine skewed	0.93	Mesokurtic
30	59	1.62	Medium	0.48	Well	0.16	Fine skewed	1.23	Leptokurtic
31	13	2.07	Fine	0.45	Well	0.08	Near symmetrical	1.13	Leptokurtic
32	14	2.18	Fine	0.73	Moderately	-0.50	Strongly coarse skewed	1.75	Very Leptokurtic
33	8	1.63	Medium	0.56	Moderately	-0.03	Near symmetrical	0.99	Mesokurtic

S. No.	Sample Number	Graphic Mean (Mz) ϕ		Sorting (σ1) ϕ		Skewness (SK1)		Kurtosis (KG)	
				KHORI-MALAN SANDSTONE					
34	4	2.68	Fine	0.38	Well	0.19	Fine skewed	1.05	Mesokurtic
35	32'	3.14	Very fine	0.49	Well	0.19	Fine skewed	0.81	Platykurtic
36	33'	2.06	Fine	0.78	Moderately	0.26	Fine skewed	1.05	Mesokurtic
37	34'	3.62	Very fine	0.41	Well	-0.02	Near symmetrical	1.18	Leptokurtic
38	39	1.02	Coarse	0.63	Moderately Well	0.24	Fine skewed	1.60	Very Leptokurtic
39	40	3.13	Very fine	0.345	Very Well	0.22	Fine skewed	1.05	Mesokurtic
40	45	3.21	Very fine	0.41	Well	0.07	Near symmetrical	0.87	Platykurtic
41	53'A	3.16	Very fine	0.62	Moderately Well	0.09	Near symmetrical	1.31	Leptokurtic
42	49	2.17	Fine	0.55	Moderately Well	-0.12	Coarse skewed	0.83	Platykurtic
43	52	3.46	Very fine	0.42	Well	-0.12	Coarse skewed	0.89	Platykurtic
44	46A	3.46	Very fine	0.44	Well	-0.21	Coarse skewed	0.84	Platykurtic
				JIRAN SANDSTONE					
45	9B	2.73	Fine	0.90	Moderately	-0.33	Strongly Coarse	1.91	Very Leptokurtic
46	10	2.72	Fine	0.53	Moderately Well	-0.41	Strongly Coarse	2.30	Very Leptokurtic

S. No.	Sample Number	Graphic Mean (Mz) ϕ		Sorting (σ_1) ϕ		Skewness (SK_1)		Kurtosis (K_G)	
47	11	2.84	Fine	0.31	Very Well	-0.38	Strongly coarse	1.08	Mesokurtic
48	25'	2.88	Fine	0.48	Well	-0.147	Coarse	1.67	Very Leptokurtic
49	27'	3.33	Very fine	0.347	Very Well	-0.13	Coarse	1.17	Leptokurtic
50	26'	1.78	Medium	0.51	Moderately Well	0.03	Near symmetrical	1.08	Mesokurtic
51	23	3.90	Very fine	0.33	Very Well	-0.06	Near symmetrical	1.60	Very Leptokurtic
52	24	3.12	Very fine	0.45	Well	0.16	Fine	0.93	Mesokurtic
53	25	3.23	Very fine	0.40	Well	0.12	Fine	0.91	Mesokurtic
54	57'	3.29	Very fine	0.42	Well	-0.02	Near symmetrical	0.81	Platykurtic
55	29'	3.12	Very fine	0.52	Moderately Well	-0.09	Near symmetrical	1.34	Leptokurtic

Table - 4 Classification of Lower Vindhyan Sandstone samples as to normality of distribution

A. MEAN SIZE

Formation / Member	Coarse (Mz 0.0 to 1.0 ϕ)	Medium (Mz 1.0 to 2.0 ϕ)	Fine (Mz 2.0 to 3.0 ϕ)	Very fine (Mz 3.0 to 4.0 ϕ)	Total
Khardeola Sandstone	-	5	6	1	12
Bhagwanpura Sandstone	-	1	1	-	2
Sawa Sandstone	1	14	4	-	19
Khori-Malan Sandstone	1	-	3	7	11
Jiran Sandstone	-	1	4	6	11
Total	2	21	18	14	55

B. SORTING

Formation / Member	Very Well Sorted (σ_1 0.35 ϕ)	Well Sorted (σ_1 0.35 to 0.50 ϕ)	Moderately Well Sorted (σ_1 0.50 to 0.71 ϕ)	Moderately Sorted (σ_1 0.71 to 1.0 ϕ)	Total
Khardeola Sandstone	2	7	1	2	12
Bhagwanpura Sandstone	-	1	1	-	2
Sawa Sandstone	-	4	4	11	19
Khori-Malan Sandstone	1	6	3	1	11
Jiran Sandstone	3	4	3	1	11
Total	6	22	12	15	55

C. SKEWNESS

Formation / Member	Strongly Coarse Skewed (SKi -1.00 to -0.30)	Coarse Skewed (SKi -0.30 to -0.10)	Near symmetrical (SKi -0.10 to 0.10)	Fine Skewed (SKi 0.10 to 0.30)	Strongly fine skewed (SKi 0.30 to 1.00)	Total
Khardeola Sandstone	-	2	3	7	-	12
Bhagwanpura Sandstone	-	-	1	-	1	2
Sawa Sandstone	1	4	8	6	-	19
Khori-Malan Sandstone	-	3	3	5	-	11
Jiran Sandstone	3	2	4	2	-	11
Total	4	11	19	20	1	55

D. KURTOSIS

Formation / Member	Platykurtic (KG 0.67 to 0.90)	Mesokurtic (KG 0.90 to 1.11)	Leptokurtic (KG 1.11 to 1.50)	Very Leptokurtic (KG 1.50 to 3.00)	Total
Khardeola Sandstone	1	8	2	1	12
Bhagwanpura Sandstone	-	2	-	-	2
Sawa Sandstone	4	10	4	1	19
Khori-Malan Sandstone	5	3	2	1	11
Jiran Sandstone	1	4	2	4	11
Total	11	27	10	7	55

Table - 5 Characteristics of subpopulations of Grain size distribution of Lower Vindhyan Sandstone in Bhadesar - Nimbahera area, Southeastern Rajasthan (after Visher, 1969) (C.T. = Coarse Truncation point, F.T. = Fine Trunction point)

S. No.	Sample Number	Saltation Population					Suspension Population			Surface Creep Population			
		Percent	No. of popula-tion	Sorting	C.T. phi(ϕ)	F.T. phi(ϕ)	Percent	Sorting	F.T. phi(ϕ)	Percent	Sorting	C.T. phi(ϕ)	F.T. phi(ϕ)
						KHARDEOLA SANDSTONE							
1	66	65	2	Fair Good	1.0	2.48	22	Excellent	3.5	15	Fair	0.5	1.0
2	3'	41	2	Poor Good	2.0	3.5	1.0	Good	4.0	58	Excellent	1.0	2.0
3	5'	67	2	Excellent	1.0	2.0	1.0	Excellent	2.5	32	Good	0.5	1.0
4	69	47	2	Fair Good	1.5	2.5	5.0	Excellent	3.0	48	Good	0.5	1.5
5	70	54	2	Excellent Good	1.7	3.0	1.7	Excellent	3.5	44	Excellent	1.0	1.75
6	71	91	2	Good Excellent	1.5	3.0	3.0	Good	4.0	6	Good	1.0	1.5
7	59'	45	2	Poor Good	1.7	4.0	1.0	Excellent	4.5	54	Fair	0.5	1.75
8	45'	61	1	Excellent	2.35	3.0	5.0	Good	4.0	34	Good	1.0	2.35
9	46'	51	2	Good Excellent	2.0	3.0	3.0	Excellent	3.5	46	Excellent	0.8	2.0
10	62	46	1	Excellent	3.0	3.5	30.0	Excellent	4.5	24	Excellent	2.5	3.0
11	42'B	85	2	Good Excellent	1.0	2.5	1.0	Excellent	3.0	14	Good	0.0	1.0
12	3	60	1	Fair	1.0	2.5	22.0	Good	4.0	18	Poor	-1.0	1.0

S. No.	Sample Number	Saltation Population					Suspension Population			Surface Creep Population			
		Percent	No. of population	Sorting	C.T. phi(ϕ)	F.T. phi(ϕ)	Percent	Sorting	F.T. phi(ϕ)	Percent	Sorting	C.T. phi(ϕ)	F.T. phi(ϕ)
						BHAGWANPURA SANDSTONE							
13	100	56	1	Fair	1.5	3.0	3.0	Excellent	3.5	41	Excellent	1.0	1.5
14	104	23	2	Poor Good	2.5	3.5	2.0	Excellent	4.0	75	Good	1.5	2.5
						SAWA SANDSTONE							
15	60'	51	2	Good Poor	1.5	3.5	1	Excellent	4.0	48	Fair	0.0	1.5
16	61'	40	1	Poor	0.5	2.2	35	Excellent	3.5	25	Poor	-0.5	0.5
17	12'	26	1	Poor	1.5	2.5	14	Excellent	3.0	60	Good	0.5	1.5
18	14'	59	1	Fair	1.0	2.0	15.0	Excellent	3.0	26	Poor	-0.5	1.0
19	15'	94	2	Good Fair	0.0	3.0	2.0	Poor	3.5	4	Poor	-0.5	0.0
20	81	86	1	Fair	1.0	4.0	-	-	-	14	Poor	-1.5	1.0
21	82	73	1	Good	1.5	3.0	12	Good	4.0	15	Fair	0.5	1.5
22	7'	28	1	Fair	1.5	2.4	8	Excellent	3.0	64	Good	0.5	1.5
23	9'	18	2	Poor Fair	1.2	3.5	1.0	Excellent	4.0	81	Fair	-0.5	1.2
24	75	80	2	Good Fair	1.0	3.0	2	Excellent	3.5	18	Poor	-0.5	1.0
25	94	88	2	Good Fair	0.5	2.5	5	Excellent	3.0	7	Poor	-0.5	0.5
26	95	66	2	Poor Good	0.5	2.5	10	Fair	3.5	24	Fair	-0.5	0.5

S. No.	Sample Number	Saltation Population					Suspension Population			Surface Creep Population			
		Percent	No. of population	Sorting	C.T. phi(ϕ)	F.T. phi(ϕ)	Percent	Sorting	F.T. phi(ϕ)	Percent	Sorting	C.T. phi(ϕ)	F.T. phi(ϕ)
27	123	88	2	Fair Good	0.0	2.0	4	Excellent	2.5	8	Fair	-0.5	0.0
28	47'	73	1	Poor	0.2	2.5	10	Excellent	3.0	17	Good	-0.5	0.2
29	48'	29	1	Poor	1.5	2.5	10	Excellent	3.0	61	Good	0.5	1.5
30	59	64	2	Good	1.0	2.0	12	Poor	3.0	24	Excellent	0.5	1.0
31	8	58	1	Good	1.0	2.0	18	Excellent	3.0	24	Fair	-0.5	1.0
32	13	75	1	Good	1.5	3.0	3	Excellent	3.5	22	Excellent	1.0	1.5
33	14	82	2	Poor Good	0.5	2.7	7	Excellent	3.5	11	Fair	-0.5	0.5
					KHORI-MALAN SANDSTONE								
34	4	90	2	Excellent Fair	2.0	3.5	4	Excellent	4.0	6	Poor	1.0	2.0
35	32'	26	1	Fair	3.0	3.5	16	Excellent	4.5	58	Excellent	2.0	3.0
36	33'	62	1	Fair	1.5	3.5	2	Excellent	4.0	36	Poor	-1.0	1.5
37	34'	86	2	Excellent	2.5	4.0	14	Fair	4.5	-	-	-	-
38	39	2	1	Poor	1.5	2.8	5	Excellent	3.5	92	Good	-0.5	1.5
39	40	82	1	Good	2.2	3.3	13	Excellent	4.0	5	Poor	1.0	2.2
40	45	66	1	Excellent	3.0	4.5	-	-	-	34	Good	2.0	3.0
41	53'A	54	1	Fair	2.2	3.5	24	Excellent	4.5	20	Poor	0.0	2.2
42	49	31	1	Excellent	2.3	3.0	2	Good	4.0	67	Good	1.0	2.3
43	52	78	1	Good	3.0	4.5	1	Good	4.5	21	Excellent	2.5	3.0

S. NO.	Sample Number	Saltation Population					Suspension Population			Surface Creep Population			
		Percent	No. of population	Sorting	C.T. phi (ϕ)	F.T. phi (ϕ)	Percent	Sorting	F.T. phi (ϕ)	Percent	Sorting	C.T. phi (ϕ)	F.T. phi (ϕ)
44	46A	61	1	Good	3.0	4.0	17	Excellent	5.0	22	Excellent	2.5	3.0
						JIRAN SANDSTONE							
45	9B	79	2	Good Excellent	2.2	4.0	1.0	Good	4.5	20	Poor	-0.5	2.2
46	10	69	2	Excellent	2.5	3.5	1.0	Excellent	4.0	30	Poor	0.5	2.5
47	11	100	1	Excellent	2.5	3.5	-	-	-	-	-	-	-
48	25'	78	2	Gcod Excellent	2.5	4.0	2	Excellent	4.5	20	Fair	1.0	2.5
49	27'	72	1	Excellent	2.5	3.5	28	Excellent	4.0	-	-	-	-
50	26'	84	2	Good	1.0	3.0	1.0	Excellent	3.5	15	Fair	0.0	1.0
51	23	56	1	Excellent	3.0	4.0	30	Good	5.0	14	Good	3.0	3.5
52	24	96	2	Good Excellent	2.0	4.0	3.0	Excellent	4.5	1.0	Poor	1.5	2.0
53	25	65	1	Good	3.0	4.0	2.0	Good	5.0	33	Excellent	2.5	3.0
54	57'	36	1	Good	3.0	3.5	27	Excellent	4.5	37	Excellent	2.5	3.0
55	29'	70	1	Good	2.5	3.5	17	Excellent	4.5	13	Poor	1.5	2.5

and Ward (1957). Table - 4 provides information on the variation of these size parameters for Khardeola, Bhagwanpura, Sawa, Khori-Malan and Jiran Sandstones.

Different scatter (Bivariate) plots like mean size versus standard deviation, mean size versus skewness, standard deviation versus skewness, kurtosis versus standard devtiation and kurtosis versus mean size were drawn by combining two statistical grain size parameters. These scatter plots (Fig. 15 to 18) were employed to interpret the depositional processes and environment. These different scatter plots were compared with those of Folk and Ward (1957), Friedman (1961, 1967, 1979) and Moiola and Weiser (1968). Friedman (1961, 1967) has used the scatter plots of moment parameters to differentiate between river and beach sands. Moiola and Weiser (1968) have considered that the plotting of skewness versus mean size provides an effective discrimination between beach and dune sediments.

Result and interpretation of size Analysis. - The statistical parameters thus determined were used in defining grain size characteristics of sandstone are listed in Table - 3. A number of statistical plots were generated from these parameters rigor of the sedimentological data are presented in Figure 15 to 18. The inferences from these analysis are described formation wise.

KHARDEOLA SANDSTONE

The size frequency distribution of Khardeola Sandstone in phi (ϕ) size grade has been furnished in Appendix - I. Of the 12 samples analysed, 11 show a near normal and unimodal size frequency distribution, while only one is weakly bimodal. Out of 12 samples, in 6 samples the modal class lies in the 1.0 to 1.5 ϕ class, in 3 samples in 1.5 to 2.0 ϕ class, in 2 samples in 2.0 to 2.5 ϕ class and in the remaining one sample the modal class lies in 3.0 to 3.5 ϕ class. The modal class contains 23.55 to 53 percent (average 39.66 percent) of the total number of the grains measured. The grain size varies from 1.42 to 3.39 ϕ (Table - 3 & 4) falling in medium to very fine sand grade (Wentworth in Folk, 1980).

The inclusive graphic standard deviation ranges from 0.33 to 0.90 which shows that two sample are very well sorted, 7 samples are well sorted, one sample moderately well sorted and remaining 2 samples are modertely sorted (Table - 4). This indicates very well to moderately sorted nature of the sandstone (Hodgson and scott, 1970; Folk, 1980) and suggests their deposition correspond to littoral and nearshore environment (Inman and Chamberlain, 1955; Friedman, 1961, 1979).

The inclusive graphic skewness value ranges from - 0.14 to 0.30 which shows that 7 samples are fine skewed, 2 samples are coarse skewed and remaining 3 samples are near symmetrical (Table - 4). The positive to negative skewness of the samples indicates nearshore environment (Freidman, 1961, 1967, 1979).

The graphic Kurtosis value ranges from 0.89 to 1.78 (Table - 3). Out of 12 samples 8 show mesokurtic, 2 leptokurtic, one very leptokurtic and remaining one show platykurtic distribution (Table - 4). The kurtosis values vary from platykurtic to very leptokurtic indicates good peakedness, *the micro variations indicate that with increasing* in grain size there is a tendency of migration from mesokuritc to leptokurtic showing the better winnowing action of the fine grains (Fig. 15 F).

The Scatter plots (Fig. 15 C, E & F) suggest the nearshore environment of the Khardeola sandstone (Friedman, 1961, 1967, 1979; Moiola and Weiser, 1968; Hodgson and Scott, 1970; Friedman and Sanders, 1978; Friedman and Johnson, 1982).

The cumulative frequency curves (Fig. 12) drawn on probability scale for grain size distribution are characterised by all the three subpopulation, i.e. suspension, saltation and traction (Visher, 1969; Friedman and Johnson, 1982). The traction load is present in all samples and varies between 6 and 58 percent in a size range from - 1.0 ϕ to 3.0 ϕ (Table - 5). Saltation being the major population constitutes 41 to 91 percent with size variation between 1.0 ϕ and 3.5 ϕ. The suspension load varies from 2.0 ϕ to 4.5 ϕ and constitutes 1 to 22 percent of the total bulk. The cumulative curves have also close similarity with the cumulative curves of foreshore beach, surf zone and shoal area of Visher (1969). These cumulative curves are also interpreate that Khardeola Sandstone may be deposited into foreshore beach, surf zone or breaking zones of nearshore and shoal area of tidal inlet environment (Visher, 1969; Friedman and Johnson, 1982).

BHAGWANPURA SANDSTONE

The size frequency distribution of Bhagwanpura Sandstone

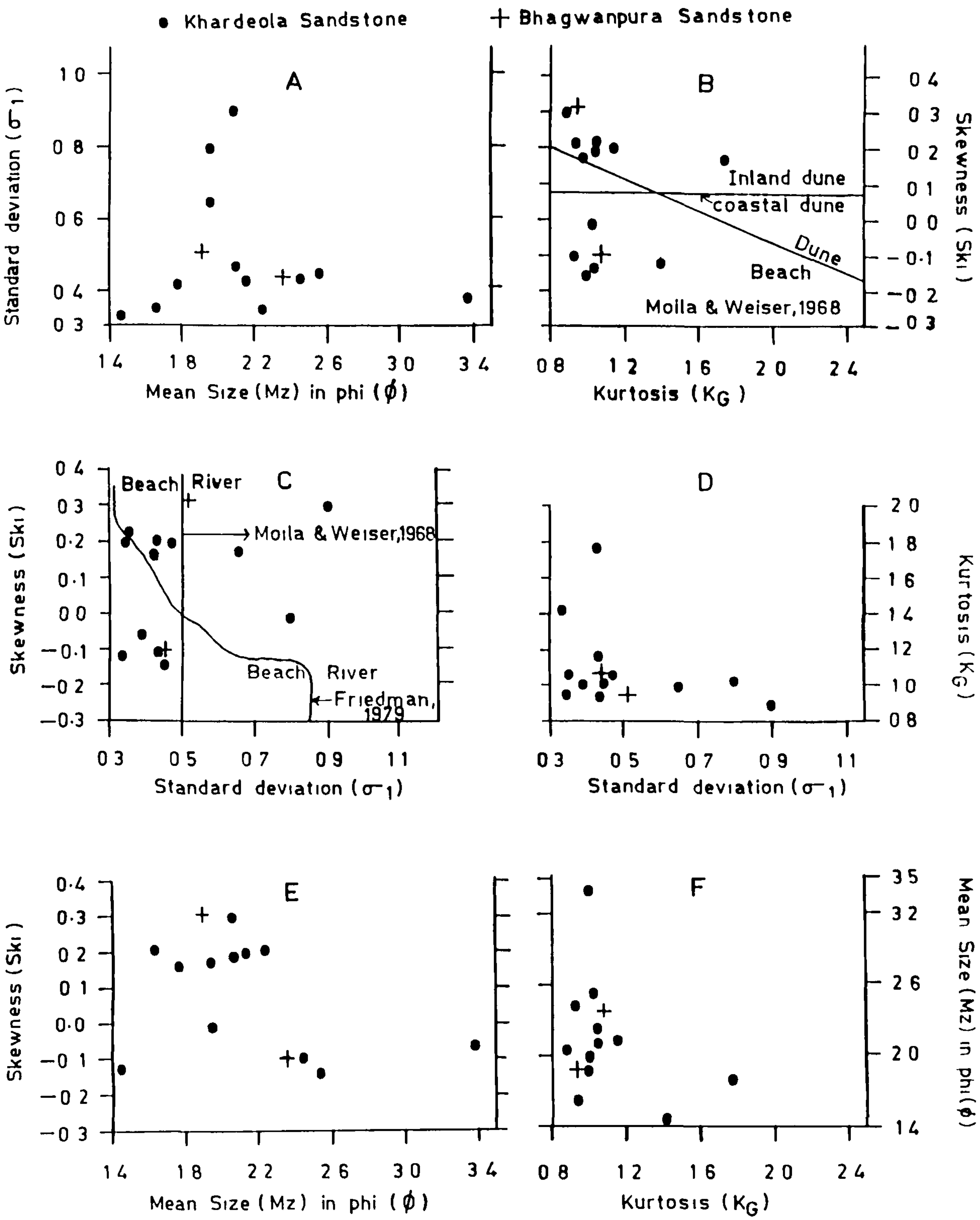

Fig 15 Scatter plots of the interrelationship of various grain size parameters of the Khardeola and Bhagwanpura Sandstones.

are Unimodel to bimodel. The grain size varies from 1.92 to 2.38 ϕ (Table - 3) falling in medium to fine grained (Wentworth in Folk, 1980). The standard deviation (0.44 to 0.51) indicates well to moderately well sorted nature of the sandstone. The positive to negative (0.31 to - 0.10) skewness of the samples indicates nearshore environment (Friedman, 1961, 1967, 1979). The Scatter plots of statistical parameters (Fig. 15 A, B, D & F) suggest that the Bhagwanpura Sandstone may be deposited in to beach or tidal inlet environments (Friedman, 1961, 1967; Moiola and Weiser, 1968; Daboll, 1969; Friedman and Sanders, 1978; Friedman and Johnson, 1982; Boothroyd, 1985). The cumulative frequency curves drawn on probability paper for grain size distribution is also interpreate that Bhagwanpura Sandstone may be deposited in to beach and tidal inlet environments (Visher, 1969; Friedman and Johnson, 1982).

SAWA SANDSTONE

The size frequency distribution of Sawa Sandstone in phi (ϕ) size grade has been furnished in Appendix - I. Of the 19 samples analysed, 10 show unimodal, 8 are bimodal and remaining one is trimodal size frequency distribution. Out of 19 samples, in 8 samples the modal class lies in 1.0 to 1.5 ϕ class, in 3 samples in 1.5 to 2.0 ϕ class, in 6 samples in 2.0 to 2.5 ϕ class and in remaining two samples in each, the modal class lies in 0.0 to 0.5 ϕ and 0.5 to 1.0 ϕ class respectively. The modal class contains 21.0 to 43.14 percent (average 30.95 percent) of the total number of the grains measured. The grain size varies from 0.85 to 2.23 ∅ (Table - 3 & 4) falling in coarse to fine grade (Wentworth in Folk, 1980).

The Standard deviation (0.45 to 0.97) indicates well to moderately sorted nature of the sandstone (Hodgson and Scott, 1970; Folk, 1980) and suggests their deposition under beach environment (Hodgson & Scott, 1970). The standard deviation decreases with decrease in grain size (Fig. 16 A) suggesting the comparatively better sorting of the finer grains/upper horizons.

The positive to negative (0.29 to - 0.50) skewness of the samples indicate ocean beach environment (Friedman, 1961, 1967, 1979) (Fig. 16 D). The Kurtosis values (0.71 to 1.75) indicate appreciable peakedness and bimodality (Table - 4).

The scatter plots (Fig. 16 B, D, F) suggest the ocean beach environment of the sandstone (Friedman, 1961, 1967; Friedman and Sanders, 1978; Friedman and Johnson, 1982 and Moiola and Weiser, 1968) or the Scatter plot (Fig. 16 A) suggest tidal inlet or large tidal creek environment of the sandstone (Daboll, 1969; Boothroyd, 1985).

The cumulative frequency curves (Fig. 13) drawn on probability scale for grain size distribution are charaterised by all the three subpopulation i.e. suspension, saltation and traction (Visher, 1969; Friedman and Johnson, 1982). The traction load is present in all samples and varies between 4 and 64 percent in a size range from - 1.5 to 1.5 ∅. Saltation being the major population constitutes 18 to 94 percent with size variation between 0.0 - 4.0 ∅. The suspension load varies from 2.5 to 4.5 ∅ and constitutes 1 to 35 percent of the total

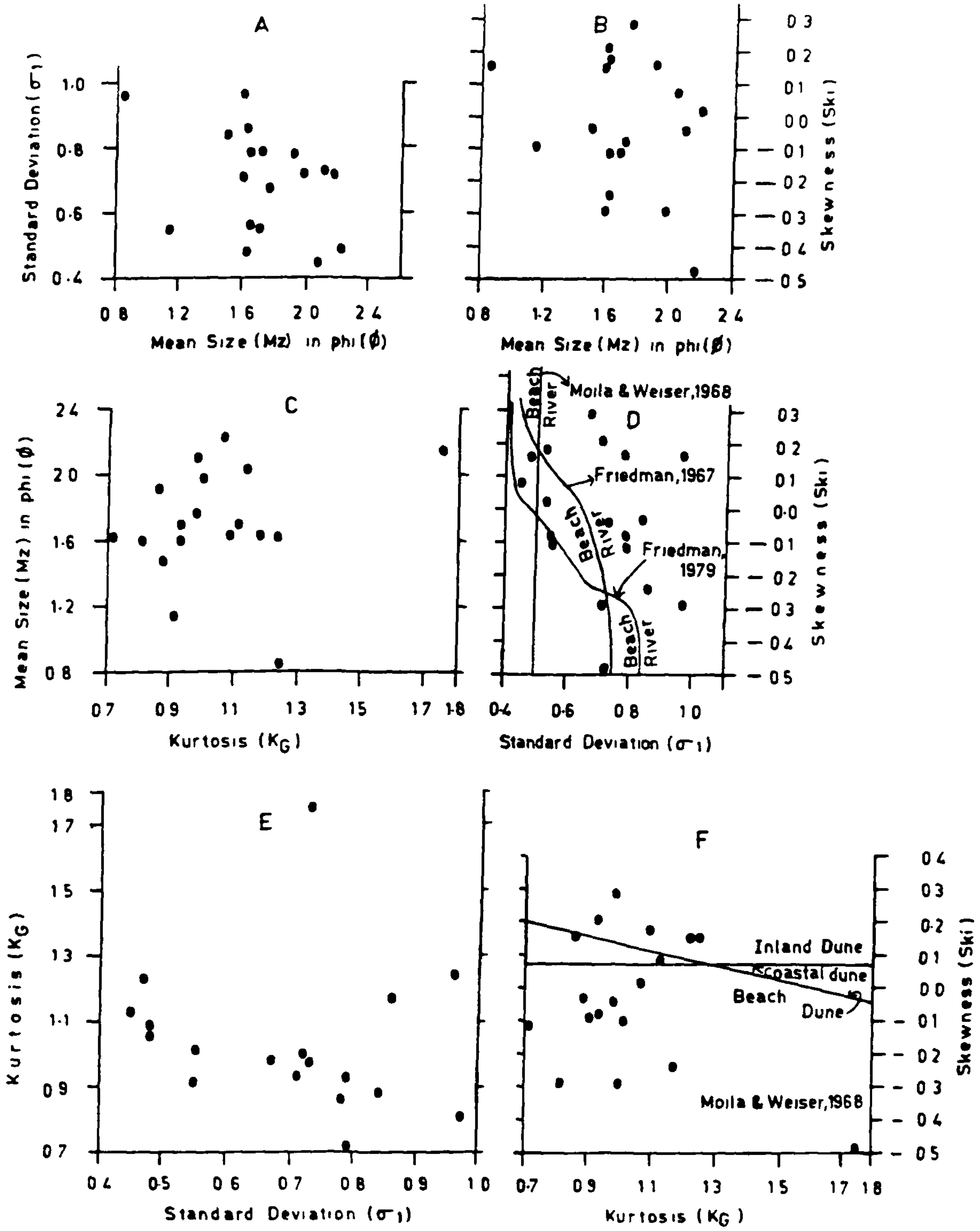

Fig 16 Scatter plots of the inter-relationship of various Grain size parameters of the Sawa Sandstone.

bulk (Table - 5). These cumulative curves are interpreate that Sawa Sandstone may be deposited into surf zone, foreshore beach, wave current zone and tidal inlet environments (Visher, 1969; Friedman and Johnson, 1982).

KHORI-MALAN SANDSTONE

The size frequency distribution of Khori-Malan Sandstone is spread to 6 to 11 half phi classes. In 8 samples, it is by and large symmetrical and unimodal, while in 3 samples it is weakly bimodal. Out of 11 samples analysed, in 3 samples the modal class lies in the 2.5 to 3.0 ϕ class, in 3 samples in 3.5 to 4.0 ϕ class, in 2 samples in 2.0 to 2.5 ϕ class and remaining 3 samples each lies in 0.5 to 1.0 ϕ class, 1.0 to 1.5 ϕ class and 3.0 to 3.5 ϕ class respectively. The modal class contains 24.70 to 46 percent (average 37.45 percent) of the total number of the grains measured. The grain size varies from 1.02 to 3.62 ϕ (Table - 3 & 4) falling in coarse to very fine sand grade (Wentworth in Folk, 1980).

The inclusive graphic standard deviation ranges from 0.345 to 0.78 which shows that one sample is very well sorted, 6 samples are well sorted, 3 samples modertely well sorted and remaining one sample is modertely sorted. Therefore the sand grain are very well to modertely sorted (Hodgson and Scott, 1970; Folk, 1980) & suggests their deposition under littoral and nearshore environments (Inman and Chamberlain, 1955) or beach environment (Hodgson and Scott, 1970).

The overall decrease in standard deviation with decrease in grain size (Fig. 17 A) reveals the better sorting of the

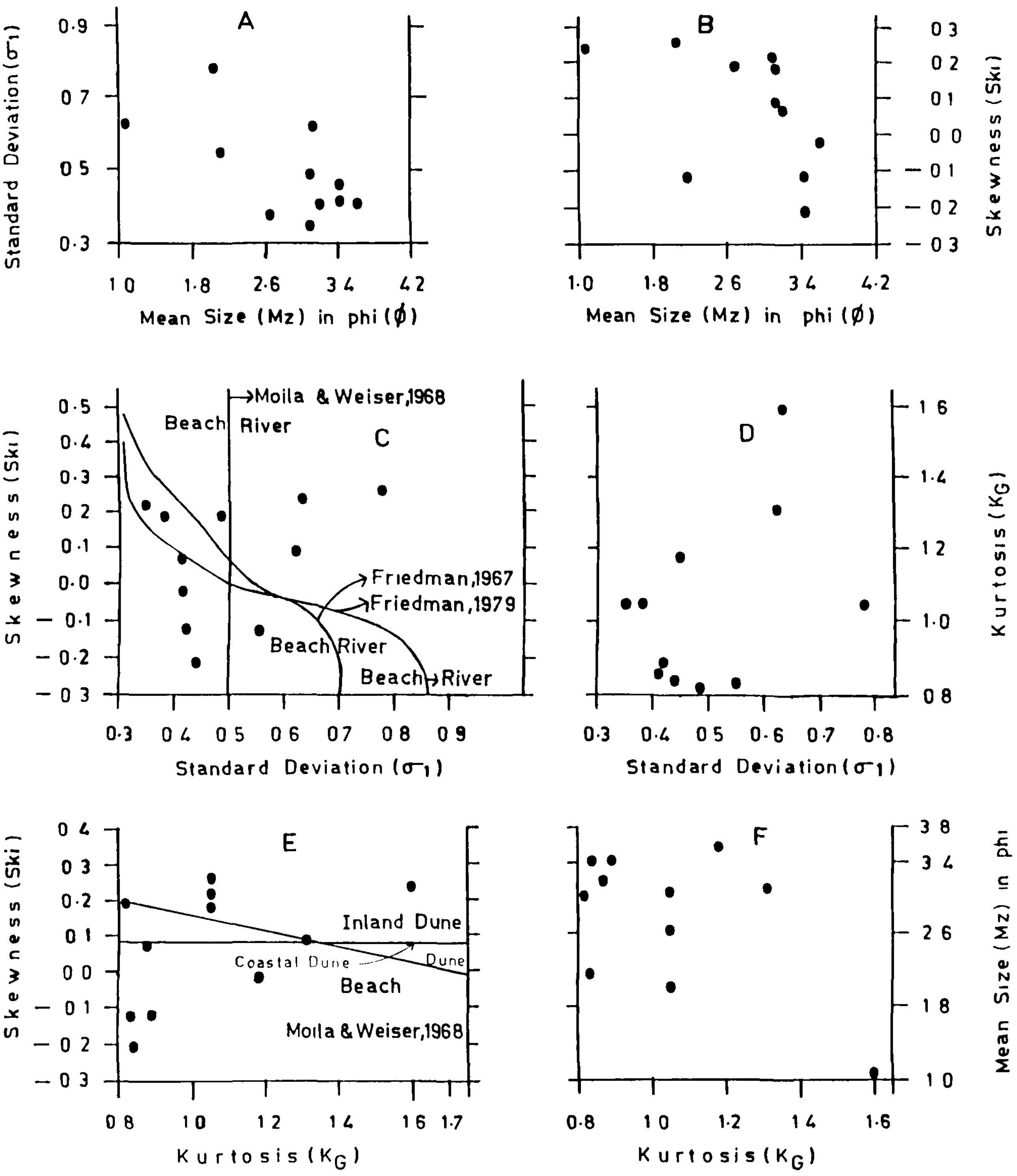

Fig 17 Scatter plots of the inter-relationship of various Grain size parameters of the Khori-Malan Sandstone.

finer grains. The anomalous decrease in standard deviation in the middle horizons of the sandstone suggest a sudden change in the environment at micro-level (Table - 4).

The inclusive graphic skewness value ranges from - 0.21 to 0.26 which shows that 3 samples are coarse skewed, 3 samples are near symmetrical and remaining 5 samples are fine skewed. The positive to slightly negative skewness of the samples indicate nearshore environment (Friedman, 1961, 1967, 1979). The Kurtosis value (0.81 to 1.60) is platykurtic to very leptokurtic indicates flat peaked and weakly bimodality.

The Scatter plots (Fig. 17 B, C & E) suggest the nearshore environment (Friedman, 1961; Friedman, 1967; Friedman and Sander, 1978; Friedman and Johnson, 1982 and Moiola and Weiser, 1968). The Scatter plot, standard deviation versus mean size (Fig. 17 A) may suggest tidal inlet or large tidal creek environment of the sandstone (Daboll, 1969; Boothroyd, 1985).

The cumulative curves (Fig. 14) reflect saltation and traction dominate the size population. The saltation population is consists of 2 to 90 percent with size variation between 1.5 to 4.5 ϕ. The traction population comprises 5 to 92 percent of the distribution with size range from - 1.0 to 3.0 ϕ. The suspension load varies from 1 to 24 percent of the total bulk (Table - 5). These cumulative curves reflect that Khori-Malan Sandstone may be deposited into beach, surf zone, tidal inlet and wave current zone environment (Visher, 1969; Friedman and Johnson, 1982).

JIRAN SANDSTONE

In contrast to the Sawa Sandstone the Jiran Sandstone is fine grained, the modal class falling in the 2.5 to 3.0 ϕ class in 7 samples, in the 3.0 to 3.5 ϕ class in 2 samples and remaining two samples each falling in the 1.0 to 1.5 ϕ class and 3.5 to 4.0 ϕ class respectively. The size frequency distribution is spread over 3 to 11 half phi classes. In 9 samples it is by and large symmetrical and unimodal while in 2 samples each show weakly bimodal and trimodal size frequency distribution. The modal class contains 34 to 68 percent (average 46.76 percent) of the total number of grains measured. The grain size varies from 1.78 to 3.90 ϕ falling in medium to very fine sand grade (Wentworth in Folk, 1980). The grain size decrease from lower to upper horizons.

The inclusive graphic standard deviation ranges from 0.31 to 0.90 which shows that 3 samples are very well sorted, 4 samples are well sorted, 3 samples are moderately well sorted and remaining one sample is moderately sorted. Therefore the sand grains are very well to moderately sorted (Hodgson and Scott, 1970; Folk, 1980) suggests their deposition under nearshore to littoral environment (Inman and Chamberlain, 1955). The decrease in standard deviation with decrease in grain size (Fig. 18 A) indicate better sorting of the finer grains forming the upper horizons.

The relationship between grain size and skewness (Fig. 18 B) show that finer grains are mostly negatively skewed and slightly coarses grains are positively skewed. This would suggest the beach environment of the finer grains mostly

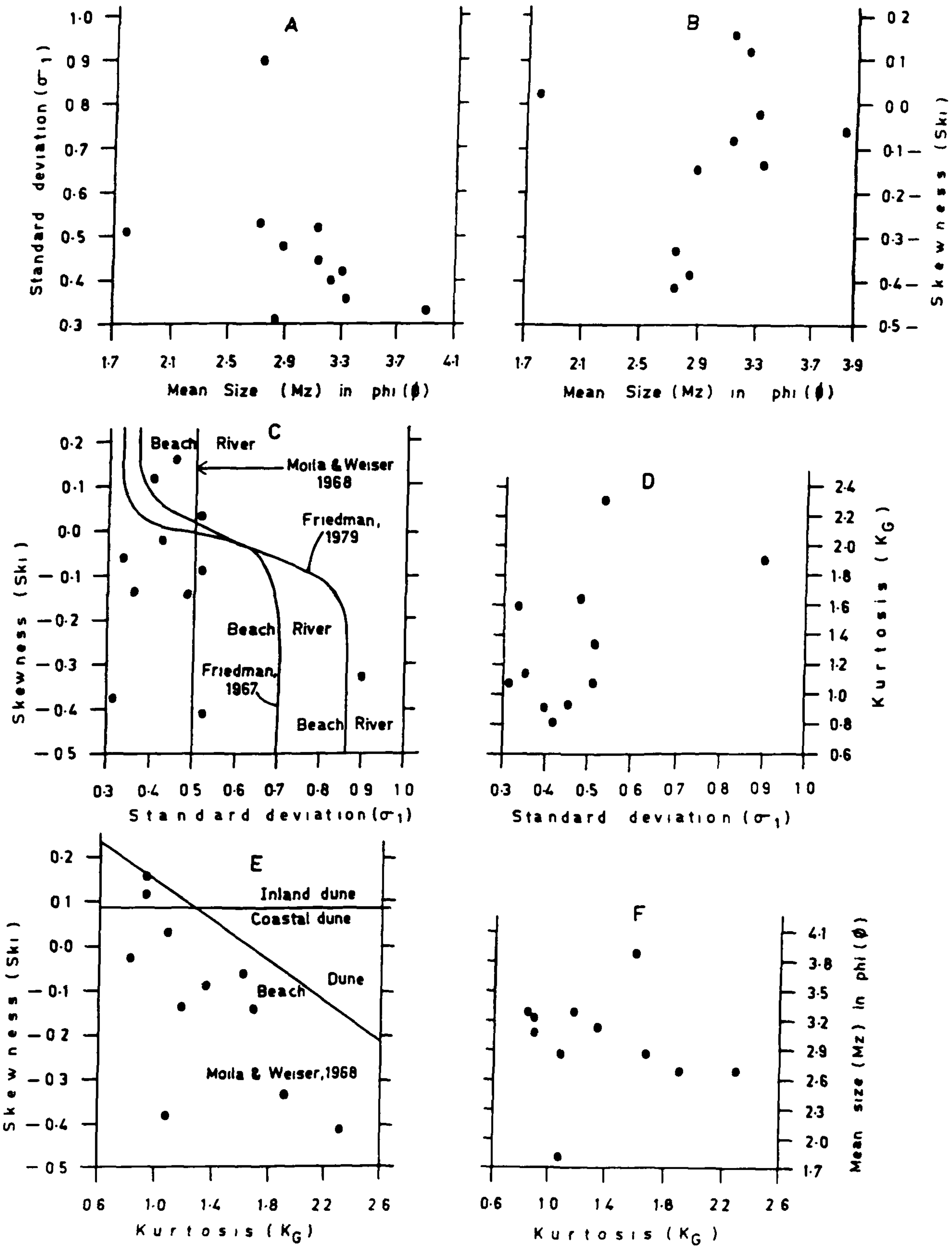

Fig 18 Scatter plots of the inter-relationship of various Grain size parameters of the Jiran Sandstone

forming the upper and middle horizons and the nearshore environment of deposition of the coarser grains constituting the lower horizons (Koldijk, 1968). The loss of peakedness of the kurtosis value is directly proportional to the increase in grain size (Fig. 18 F) indicating the better winnowing action of the finer grains.

The scatter plots (Fig. 18 A, B, C & E) suggest the ocean beach and tidal channel environment of sandstone (Friedman, 1961, 1967; Moiola and Weiser, 1968; Daboll, 1969; Hodgson and Scott, 1970; Srivastava and Mehrotra, 1981; Friedman and Johnson, 1982; Boothroyd, 1985).

The cumulative frequency curves (Fig. 14) drawn on probability scale for grain size distribution are characterised by all the three subpopulation i.e. suspension, saltation and traction (Visher, 1969; Friedman and Johnson, 1982). Saltation is being the largest population consitutes 36 to 100 percent with size variation between 1.0 to 4.0 ϕ. The traction load comprises 1 to 37 of the distribution with size range from - 0.5 to 3.5 ϕ. The suspension load varies from 1 to 30 percent of the total bulk (Table - 5). These cumulative curves are interpreate that Jiran Sandstone may be deposited in to beach, breaker zone and tidal channel environments (Visher, 1969; Friedman and Johnson, 1982).

ROUNDNESS

Roundness is an attribute of particle shape that is related to the sharpness or curvature of edges and corners. It is geometrically independent of sphericity and reflects, in part, the abrasional history of the particle. Roundness is defined by the relationship among the radii of individual edges and corners, the number of corners measured and the radius of maximum inscribed circle of the particle. Roundness of a particle is a function of distance of transport, transporting agent and environment of deposition. Since roundness reflects, in part, the abrasional history of a particle, it serves as an indicator of the number of cycles through which the particle has passed. With each cycle of erosion, transportation and deposition the particle becomes progressively rounded (Fridman and Johnson, 1982).

Methodology. - Several methods and scales for the determination of roundness of grains are available (Wadell, 1935; Russel and Tayler, 1937; Krumbein, 1941; Powers, 1953; Folk, 1980; Pettijohn, 1984). In present study the method given by Waskom (1958) has been followed. It consists of assigning on individual grains to appropriate power's classes on the basis of the modified version of the criteria originally described by Pettijohn (1957a, P. 38 - 59). Chayses (1949) point counting technique was applied for uniform coverage of a thin section for the roundness estimations and two hundred detrital quartz grains whose boundaries could be clearly distinguished from the overgrowths, were measured in each thin section and the data were grouped into power's (1953) roundness classes. The arithmetic mean roundness for each sample was calculated as described by Krumbein and Pettijohn (1938). The data on roundness of quartz grains in

Table 6 Roundness characteristics of Detrital Grains in Lower Vindhyan Sandstone of Bhadesar - Nimbahera area.

Formation/ Member	No. of Samples	Position of mode			Percentage of grains model class		Arithmetic mean roundness	
		Sub Angular	Sub Rounded	Rounded	Range	Average	Range	Average
Khardeola Sandstone	12	1	10	1	39.92-71.0	52.82	0.37-0.51	0.42
Bhagwanpura Sandstone	2	-	2	-	44.00-56.0	50.00	0.44-0.50	0.47
Sawa Sandstone	19	1	18	-	39.00-70.0	53.79	0.37-0.48	0.42
Khori-Malan Sandstone	11	1	10	-	34.81-63.0	53.33	0.33-0.47	0.39
Jiran Sandstone	11	1	10	-	37.61-77.0	57.52	0.36-0.45	0.40

Lower Vindhyan Sandstone of the study area, are based on the thin section study of 55 samples (12 from Khardeola Sandstone, 2 from Bhagwanpura, 19 from Sawa, 11 each from from Khori-Malan and Jiran Sandstones), are listed in Appendix - II. Table - 6 summaries the roundness statistics of various formations.

KHARDEOLA SANDSTONE

The detrital quartz grains in Khardeola Sandstone are angular to rounded (Appendix - II). In 10 samples out of 12, the modal class lies in the subrounded class where as in the remaining 2 samples each lies in the subangular and rounded respectively. The modal class contain 39.92 to 71.0 percent (average 52.82 percent) of the total numbers of grains measured (Table - 6). But 46.22 to 96 percent (average 75.22 percent) of the total measured grains are subrounded to rounded. The arithmetic mean roundness of grains is varies from 0.37 to 0.51 in various samples and average 0.42. A short transportation histroy is inferred from roundness values (Appendix - II and Table - 6).

BHAGWANPURA SANDSTONE

The detrial quartz grains in Bhagwanpura Sandstone are angular to well rounded. The modal class is lies in the subrounded class. The modal class contain 44 to 56 percent (average 50 percent) of the total number of grains measured.

SAWA SANDSTONE

The detrital quartz grains in Sawa Sandstone show a wide range of roundness class from Angular to well rounded classes. In 18 samples out of 19 analysed, the modal class lies in the subrounded class where as in the remaining one sample it lies in the subangular class. The modal class contains 39 to 70 percent (average 53.70 percent) of the total number of grains measured (Table - 6). But 55 to 93 percent (average 76.44 percent) of the measured grains are subrounded to rounded. The arithmetic mean roundness of grains varies from 0.37 to 0.48 and average 0.42.

KHORI-MALAN SANDSTONE

The quartz grains in Khori-Malan Sandstone are angular to rounded. In 10 samples out of 11 analysed, the modal class lies in the subrounded class where as in the remaining one sample it lies in subangular class (Appendix - II and Table - 6). The modal class contains 34.81 to 63.0 percent (average 53.33 percent) of the total number of grains measured. But 38.86 to 91.0 percent (average 68.21 percent) of the total measured grains are subrounded to rounded. The arithmetic mean roundness of grains is varies from 0.33 to 0.47 and average 0.39.

JIRAN SANDSTONE

The detrital quartz grains in Jiran Sandstone show a wide range of roundness value which are spread over 5 roundness classes from very angular to rounded. In 10 samples out of 11 analysed, the modal class lies in the subrounded class where as in the remaining one sample it lies in the subangular class. The modal class contains 37.61 to 77.00 percent (average 57.52 percent) of the total number of measured grains. But 50 to 92 percent (average 74.29 percent) of the grains are subrounded to rounded. The arithmetic mean roundness of grains varies from 0.36 to 0.45 and average 0.40.

C H A P T E R IV

P E T R O G R A P H Y A N D C L A S S I F I C A T I O N

PETROGRAPHY OF SANDSTONE

Introduction. - A very little contribution to petrography of Lower Vindhyan Sandstone of South Eastern Rajasthan has been made so far. A few authors such as Heron (1936), Coulson (1927) and Prasad (1984) however have paid less attention about petrography of the investigated area. The present petrographic study of sandstone deals with detrital mineral composition. The detrital clasts have been studied and identified to classify the sandstones.

Many workers have made attempts to categorise detrital quartz genetically because it is the chief and dominant constituent of sandstones and indicative of provenance. Sorby (1880) and Mackie (1896) were the first to study detrital quartz grains. Mackie (1896) classified detrital quartz into four groups on the basis of their inclusions. Later, Krynine (1940, 1946) genetically classified detrital quartz into igneous (plutonic, volcanic and hydrothermal vein quart), metamophic (recrystallized, schistose and stretched) and reworked sedimentary quartz on the basis of extinction, inclusions and grain shape. Krynine's Plutonic quartz was modified to 'common' quartz by Folk (1980) because much quartz from other sources (metamorphic, vein etc.) has the same characteristics. Folk (1968) also classified detrital quartz empirically on the basis of extinction and inclusions. Blatt and Christie (1963) concluded that undulatory extinction is not a reliable guide to the provenance of quartz. Fuji (1958) recognised four varieties of quartz including cryptocrystalline quartz (Chert). Many other workers also described quartz varieties (Pollack, 1961; Hayes, 1962; Fields and Weather head, 1966; Young, 1976; Basu, 1985).

Many authors (Folk and Weaver, 1952; Fuji, 1958; Folk, 1968, 1980) were described chert as microcrystalline quartz, cryptocrystalline quartz and chalcedonic quartz. Chert was grouped into four varieties : fine grained, coarse grained, specular and silty (Pettijohn et al 1987). Many workers now consider chert as rock fragment.

The significance of feldspar has been discussed in relation to source, palaeoclimate and tectonism (Martens, 1931; Russell, 1937; Krynine, 1948; Hayes, 1962; Pittman, 1963; Rim Saite, 1967; Folk, 1968, 1980; Field and Pilkey, 1969; Pettijohn et al, 1987; Dickinson, 1985). Authigenic feldspar is believed to be a Criterion of recognising marine origin (Crowley, 1939). The importance of Metamorphic, Sedimentary and Volcanic rock fragments were described by Folk (1980); Pettijohn et al (1987) and Pettijohn (1984).

Although, heavy minerals occurs as accessory constituents of normal sandstone, they are considered to be useful guide to the type of source rcck. Keeping this view in mind some definite assemblages of heavy minerals were described and related to their probable source rcck (Boswell, 1933; Krumbein and Pettijohn, 1938; Feo-Codecido, 1956; Pettijohn, 1957; Todd and Folk, 1957; Fuji, 1958; Ijima, 1959; Baker, 1962; Okada, 1960, 1961, 1967; Folk, 1980; Mccarley, 1981).

Methodology. - In the present study detrital and authigenic minerals composition of sandstone was evaluated both qualitatively and quantitatively. 48 thin sections (11 from Khardeola Sandstone, 2 from Bhagwanpura, 16 from Sawa, 9 from Khori-Malan and 10 from Jiran Sandstones) were selected to determine the modal composition and other petrographic characters of the sandstone. These samples were selected in such a way so as to cover uniformly both laterally and vertically, the outcrops of the five formations. Thin sections of sandstone were quantitatively analysed for their percentage composition using a swift automatic point counter fitted to a petrological microscope. About 200 grains were counted as described by chayes (1949) was employed for a uniform coverage of thin section. The volumetic proportions of the various constituents of the sandstone are listed in Appendix - III.

Mineral Composition. - Mineral composition of all the sandstones was determined in thin section study. Terminology of Krynine (1940) and Folk (1980) was followed for describing several varieties of quartz and other framework constituents. Nearly all the studied sandstones are composed of varieties of quartz, followed by feldspar, chert, heavy mineral and micas. The deterital mineral are described in the order of their abundance.

COMMON QUARTZ (CQ)

The sandstones under study consists dominantly of common quartz. It constitutes from 30.45 to 81.65% (average 55.37%) by volume in Khardeola Sandstone, 47.46 to 54.41% (average

51%) in Bhagwanpura, 3.75 to 80.55% (average 41.96%) in Sawa Sandstone, 1.07 to 71.70% (average 42.06%) in Khori-Malan Sandstone and from 1 to 88% (average 58.54%) by volume in Jiran Sandstone.

It occurs as irregular subequant and mostly subrounded to angular grains (Plate 19, Fig. 1). But subangular and rounded grains are also common (Plate 19, Fig. 2). The quartz shows stright to slightly undulose extinction. Some randomly scattered vacuoles are common. Mineral inclusion of micas, Zircon, tourmaline and opaques mineral are present less frequently as inclusions. This type of quartz was termed as plutonic quartz by Krynine (1940) and common quartz by Folk (1968, 1980).

RECRYSTALLIZED METAMORPHIC QUARTZ (RMQ)

Quartz comprises 0.0 to 30.0% (average 6.27%) by volume in Khardeola Sandstone, 0.0 to 12.5% (average 6.25%) in Bhagwanpura Sandstone 0.0 to 27.86% (average 6.16%) in Sawa Sandstone, 0.0 to 13.21% (average 3.87%) in Khori-Malan Sandstone and 0.0 to 25.0% (average 4.26%) by volume in Jiran Sandstone.

It occurs as composite grains (Plate 19, Fig. 3) of fine to medium size and equant to subequant shape. The quartz grains are made up of a mosaic of microcrystalline to fine grained (Plate 19, Fig. 4). The grains are equidimensional with straight boundaries, show different optic orientation and straight extinction. The grains are mostly subrounded to rounded, but subangular grains are also common. The size and

PLATE 19

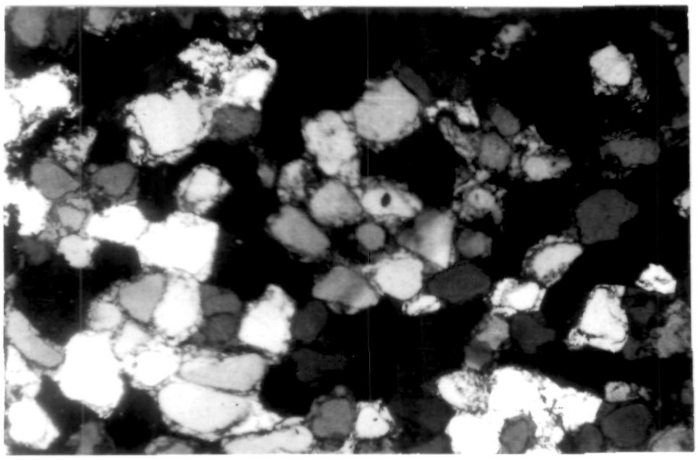

Fig.1

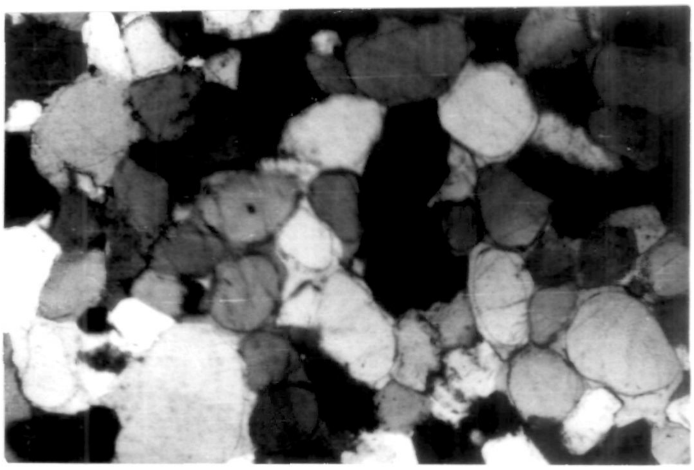

Fig.2

Fig.3

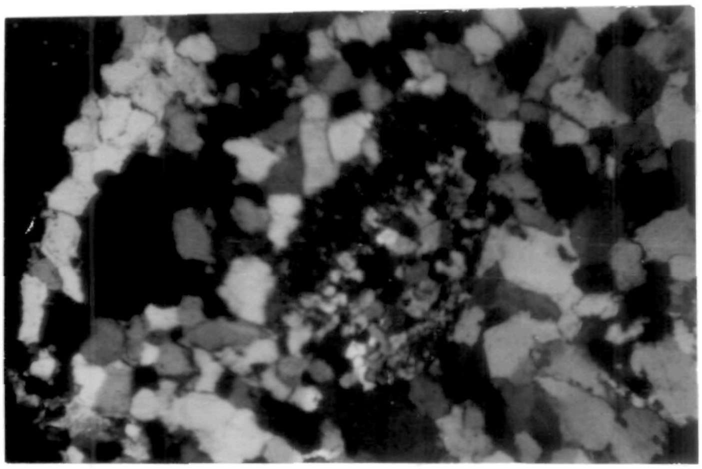

Fig.4

P L A T E - 19

Fig. 1 Photomicrograph of Khardeola Sandstone, showing angular to subrounded grains of detrital quartz grains. Crossed nicols; X 40.

Fig. 2 Photomicrograph of sandstone, showing subrounded to rounded detrital quartz grains. Note the grain contacts are generally tangential and secondary quartz form the cement. A distinction between the detrital grain and silica overgrowth is possible due to the presence of thin iron oxide coating around the former. Bhagwanpura Sandstone. Crossed nicols; X 40.

Fig. 3 Photomicrograph of Sawa Sandstone, showing polycrystalline quartz grains and weathered orthoclase altered into clay. Crossed nicols; X 40.

Fig. 4 Photomicrograph of Jiran Sandstone, showing recrystallized metamorphic quartz and chert. Crossed nicols; X 40.

roundness of RMQ grains is comparable to that of the chert grains. Presence of minute mica flakes and clay impurities are common.

STRETCHED METAMORPHIC QUARTZ (SMQ)

This type of quartz is dominant in Khori-Malan Sandstone (0.0 to 33.19% by volume, average 8.83%) and in Jiran Sandstone (0.0 to 31.15% by volume, average 3.71%) in contrast to Khardeola Sandstone (0.0 to 5.0%, average 2.05%) and Sawa Sandstone (0.0 to 13.59% by volume, average 4.68%).

It occurs as subrounded to well rounded polycrystalline grains which are mostly made up of elongated and lensoid subindividuals of quartz. The subindividuals are in subparallel to almost parallel orientation (Plate 20, Fig. 1) with smooth and sutured boundaries. The subindividuals show highly undulose extinction. Sometimes the subindividuals occur independently as monocrystalline grains which are easily recognised and distinguished from monocrystalline common quartz by characteristic features such as elongated and lensoid shape, abundant healed fractures and highly undulose extinction.

REWORKED SEDIMENTARY QUARTZ (RSQ)

It constitutes dominantly in Sawa sandstone (0.97 to 70.83%, average 22.18%) and in Khori-Malan Sandstone (1.80 to 71.66% average 22.6%), in contrast to Khardeola and Jiran Sandstone where it is 0.94 to 28.85% (average 10.0%) in former and 0.0 to 10.19% (average 1.67%) by volume in latter respectively. But in some thin sections they are not encountered at all.

It is recognised by abraded secondary overgrowths of silica on detrital quartz grains, which are formed in one or more cycles of sedimentation (Plate 20, Fig. 2). The secondary overgrowth are in optical continuity with the detrital grains but a distinction between two is generally possible due to the presence of a thin coating of iron oxide around the later (Plate 19, Fig. 2). The authigenic enlargements are predominant in unpressolved and slightly pressolved sandstones but are insignificant or entirely absent in moderately and highly pressolved specimens.

In some grains a distinction between the detrital grains and the overgrowth is not possible due to the absence of the coating of iron oxide around the grain and in all such cases the composite grains appear sharply angular.

VEIN QUARTZ (VQ)

Vein quartz is present in variable amount in Khori-Malan Sandstone (0.0 to 4.8%, average 2.03%) and in Jiran Sandstone (0.0 to 48%,average 9.33%). In contrast, some sample (about one fourth) of Khardeola and Sawa Sandstones contains vein quartz from 0.0 to 30.0% (average 2.82%) and 0.0 to 41.0% (average 3.25%) respectively.

It is commonly occurs in the form of monocrystalline grains and occasionally in semicomposite grains which were designated pseudo-polycrystalline quartz grains by Pettijohn et al (1987). Monocrystalline grains have abundant vacuoles

PLATE 20

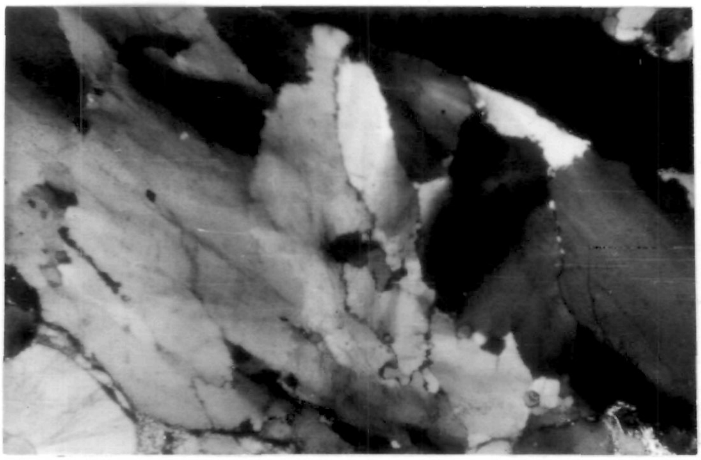

Fig. 1

Fig. 2

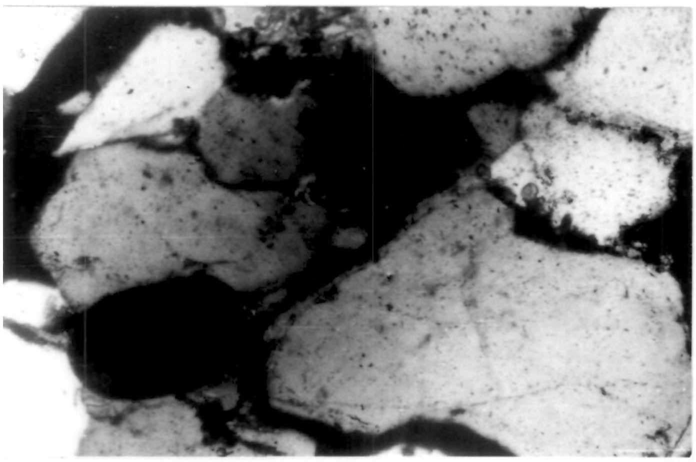

Fig. 3

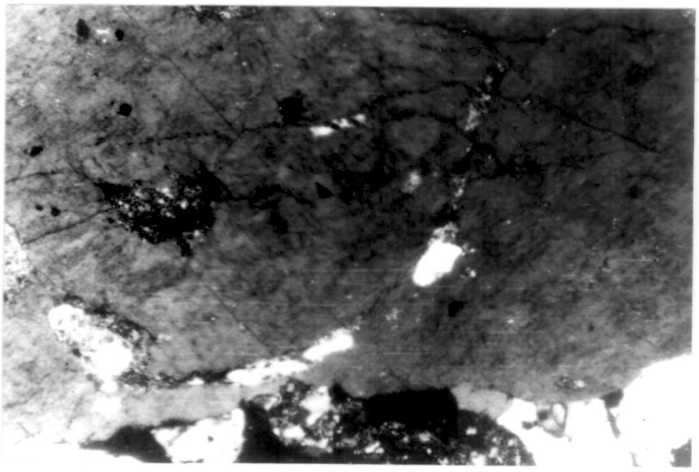

Fig. 4

P L A T E - 20

Fig. 1 Photomicrograph of Sawa Sandstone, showing elongated and lensoid subindividuals of stretched metamorphic quartz. Crossed nicols; X 40.

Fig. 2 Photomicrograph of Khori-Malan Sandstone, showing Reworked Sedimentary Quartz (RSQ). Note the quartz grain in the centre shows two cycles of overgrowth. Crossed nicols; X 100.

Fig. 3 Photomicrograph of Jiran Sandstone, showing vein quartz. Tourmaline grains are perfectly rounded. Crossed nicols; X 100.

Fig. 4 Photomicrograph of Khardeola Sandstone, showing weathered orthoclase slightly altered into clays. Crossed nicols, X 40.

giving cloudy appearance (Plate 20, Fig. 3). The grains are mostly subrounded and have straight to slightly undulose extinction.

FELDSPAR

The detrital feldspar includes both fresh and altered feldspar. Detrital feldspar are present only in traces in the Khori-Malan and Jiran Sandstone-two or three grains per thin section being encountered in some thin sections and none at all in others. In contrast the Khardeola and Sawa Sandstones contains good amounts of feldspar. In Khardeola Sandstone it varies from 1.0 to 8.49% (average 3.25%), in Bhagwanpura Sandstone 1.47 to 3.39% (average 2.43%) and in Sawa Sandstone from 1.85 to 24.51% (average 8.72%) by volume of the rock.

Three varities of feldspar have been recognised which include orthoclase, microcline and plagioclase. Orthoclase and microcline are most dominant in all the formations where as plagioclase is in traces (Plate 20, Fig. 4 & Plate 21, Fig. 1). In particle size and roundness characters, the feldspar grains are comparable to the detrital quartz grains with which they are associated in the different sandstone formations (Plate 21, Fig. 2).

Altered feldspar (orthoclase and microcline) have a dusty appearance under plane polarized light (Plate 19, Fig. 3 and Plate 21, Fig. 3). Their colour is generally some shades of brown. Feldspar is altered because of their unstable nature under deuteric hydrothermal and weathering conditions (Folk, 1980).

PLATE 21

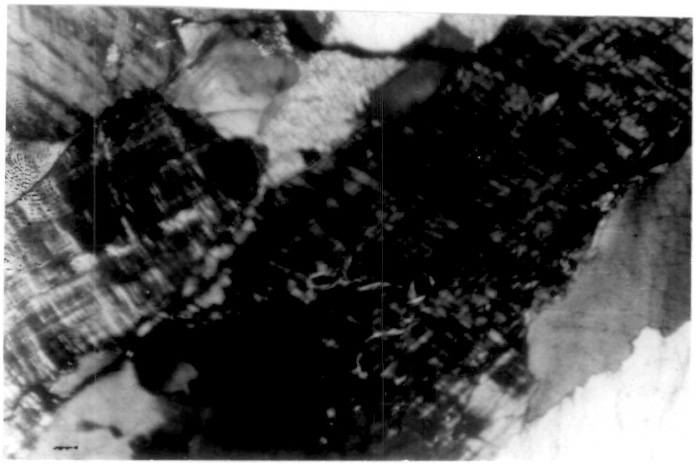

Fig.1

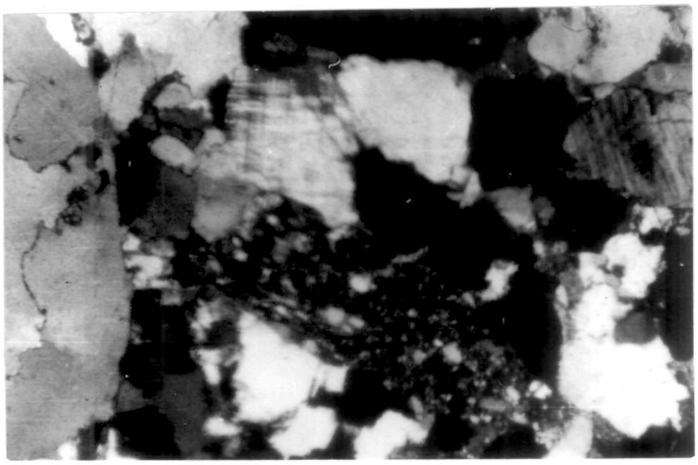

Fig.2

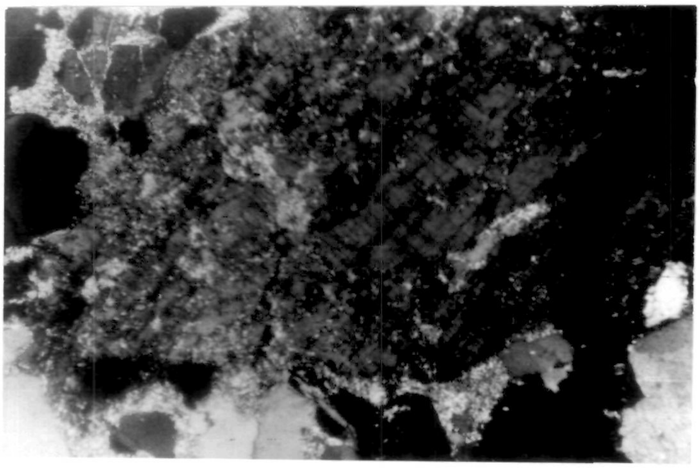

Fig.3

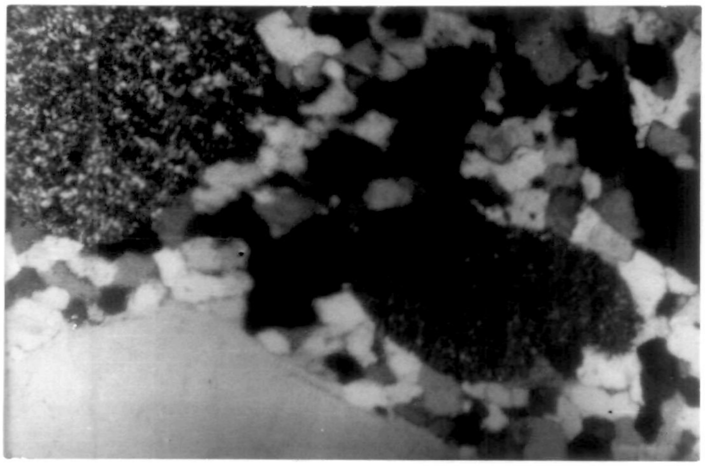

Fig.4

PLATE - 21

Fig. 1 Photomicrograph of Sawa Sandstone showing fresh and partially altered microcline. Crossed nicols; X 40.

Fig. 2 Photomicrograph of Khardeola Sandstone, showing rock fragment of shale. Note the microcline grains are subangular to subrounded and comparable in size to the detrital quartz. Crossed nicols; X 40.

Fig. 3 Photomicrograph of Sawa Sandstone, showing altered microcline grain. Crossed nicols; X 40.

Fig. 4 Photomicrograph of Jiran Sandstone showing rounded chert grain larger than detrital quartz grain. Crossed nicols; X 40.

CHERT

Chert is present in variable amounts in the different sandstone formation. In 4 out of 11 samples of Khardeola sandstone, Chert comprises 2.0 to 10.68% (average 5.32%) by volume of the rock. In 5 out of 16 samples of Sawa Sandstone, it varies from less than 1 to 7.79% (average 3.17%) by volume of the rock. Mostly all thin sections of Khori-Malan Sandstone were found to contain Chert to the extent of 0.94 to 10.81% (average 3.75%) by volume of the rock. However in Jiran Sandstone it is almost absent only one sample contain 11.69% by volume of the rock.

Mostly chert in all the samples is of detrital in origin. It occurs as subrounded to well rounded grains which are approximately smaller than the accompanying quartz grains. But in some cases it is larger or equal to quartz grains in size (Plate 21, Fig. 4). It also occurs as cementing material between the quartz grains (Plate 22, Fig. 1). Chalcedony grains show radiating extremely thin fibres under cross nicols (Plate 22, Fig. 2). Chert grains contain common impurities of clay, silt and iron oxide.

The presence of Chert like that of multicycle **quartz** indicates the presence of sedimentary/ or metasedimentary rocks in the provenance.

HEAVY MINERALS

Heavy minerals in the studied sandstone are present as traces. They include tourmaline, Zircon, opaques etc.

Tourmaline grains which are generally subrounded to well rounded (Plate 20, Fig. 3) and occasionally subangular to angular (Plate 22, Fig. 3). They show various colours such as pale brown, yellowish brown, brownish green, green and occasionally pinkish black to brownish black.

Zircon is occurs mostly in the form of subangular to rounded grains (Plate 22, Fig. 4 & Plate 23, Fig. 1). Some grains are well rounded while few are euhedral. Zircon is generally colourless and show high relief. But pale coloured varieties can also be seen. Zircon grains are smaller in size than quartz grains.

Opaques grains are magnetite, limonite, heamatite. They are mostly subrounded to well rounded, but rarely euhedral.

ROCK FRAGMENTS

Besides fragments of quartzite and chert described earlier, sedimentary and metamorphic rock fragments occur sparsely distributed. Metamorphic quartzite and quartz schist are by and large are the most common variety rock fragments present in the sandstones. All the five formation constitues rock fragments as traces. In 8 out of 48 thin sections of five formation, they comprise 0.91 to 9.22% (average 3.15%) by volume of the rock; the remaining samples contain not more than one or two grains in the entire thin section.

The sedimentary rock fragments includes fragments of chert, shale, siltstone (Plate 21, Fig. 2). They are subrounded to well rounded and their size is similar to that of surrounding quartz grains. Fragments of shale are common. Due to softness, the shale fragments have been squeezed

PLATE 22

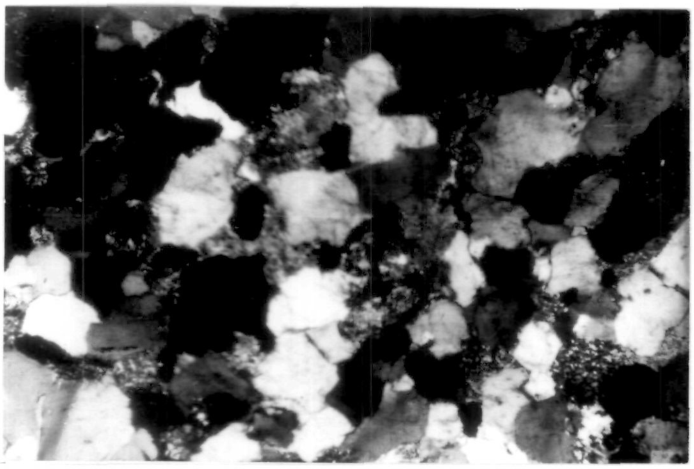

Fig.1

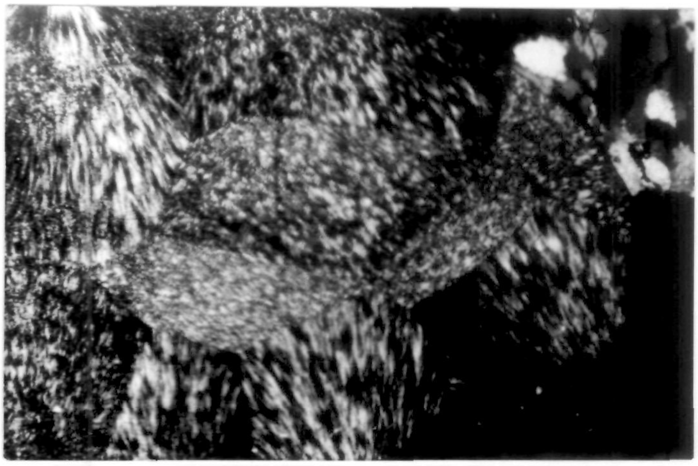

Fig.2

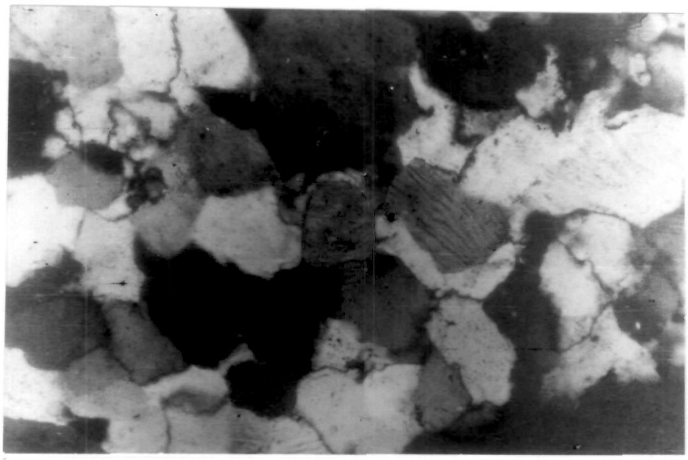

Fig.3

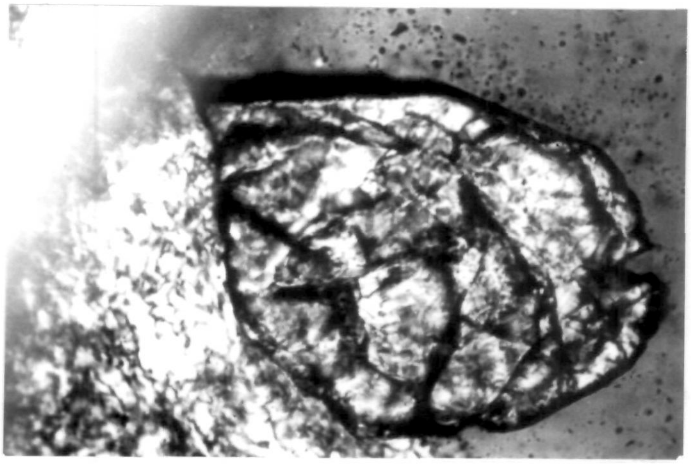

Fig.4

P L A T E - 22

Fig. 1 Photomicrograph showing chert and clay matrix as cements in Bhagwanpura Sandstone. Crossed nicols; X 40.

Fig. 2 Photomicrograph of chalcedony grain showing radiating extremely thin fibres in Khardeola Sandstone. Crossed nicols; X 100.

Fig. 3 Photomicrograph of Jiran Sandstone showing angular to subangular tourmaline grains in the normal framework of detrital quartz grains. Crossed nicols; X 100.

Fig. 4 Photomicrograph showing subangular zircon grains in Sawa Sandstone. Crossed nicols; X 400.

occasionally in between the surrounding quartz grains giving rise to pseudomatrix (Plate 23, Fig. 2).

Metamorphic rock fragments include dominantly quartz schist and quartzite. Grains of quartzite and quartz schist are uniformly, though sparsely distributed in all the sandstone formations. They are of the same order of size as the detrital quartz grains, but *are relatively rounded to subrounded than the latter.*

MICA

Mica grains occur as traces in all the five sandstone formations. They include muscovite and biotite. They are randomly distributed as grains. Muscovite is commonly occur as altered form, originated from orthoclase (Plate 23, Fig. 3). Both muscovite and biotite occur as tiny to large elongate flakes with frayed ends. The flakes occasionally show mechanical deformation as a result of pressure by the accompanying quartz grains. Biotite grains are generally brown in colour.

MINERALS CEMENTS

Three principle types of minerals cements namely silica, clay matrix and iron oxide are present in sandstones of the study area. Various types of cements are described in the order of their abundance.

Silica Cement. - Silica forms the volumetrically dominant cementing material. Silica Cement occurs into three Varieties:

Authigenic quartz, **Chert** and Opal. Authigenic quartz occurs in optical continuity with detrital quartz grains as secondary enlargements (Plate 20, Fig. 2). Chert occurs as granular mass (Plate 22, Fig. 1) and opal in spheroidal form occurs within intergranular spaces. Among the three varieties of Silica Cement, Authigenic quartz is more common than others. About 80% thin scetions contain silica cement almost to the exclusion of iron oxide.

The amount of silica cement varies from sample to sample depending upon the degree of condensation and pressure solution undergone by the rocks. Thin sections in which there is no evidence of condensation of the framework, the amount of silica cement is generally lies in the range of 20 to 25% by volume of the rock. On the other hand thin sections of moderately and highly pressolved sandstone show a very small quantity of this cement (Plate 19, Fig. 4 and Plate 23, Fig. 4), vary in amount from 2 to 12% by volume of the rock.

Clay Matrix. - After silica, clay matrix is another dominant cementing material. It occurs as matrix (Plate 22, Fig. 1) or as alteration product of feldspar (Plate 19, Fig. 3). The grain diameter was measured down to 5 ϕ (0.03 mm) and all the material less than this limit was taken as clay or matrix (Spencer, 1963). About 40% thin sections contain clay matrix. Here amount of this cement is varies from sample to sample depending upon two factors. one is condensation of the framework and another how much percentage of feldspar is present in the rock. In general, clay matrix, is varies from

PLATE 23

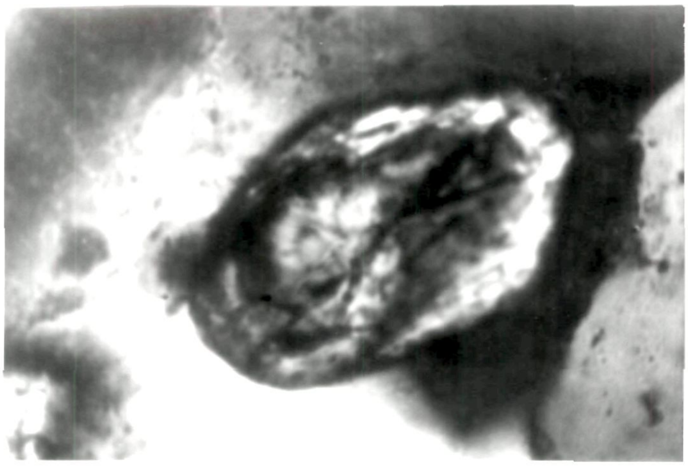

Fig.1

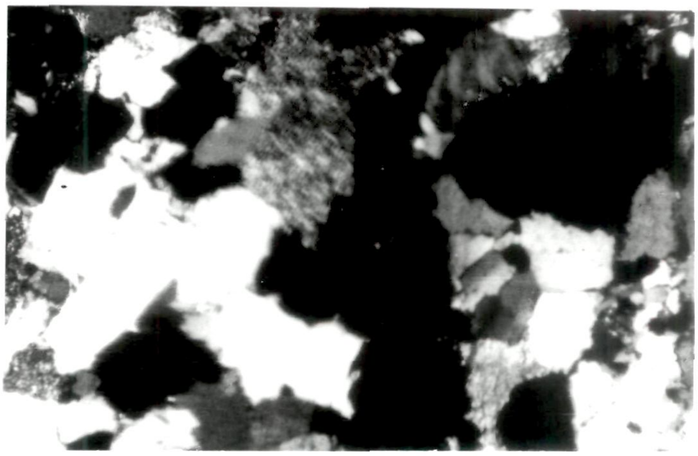

Fig.2

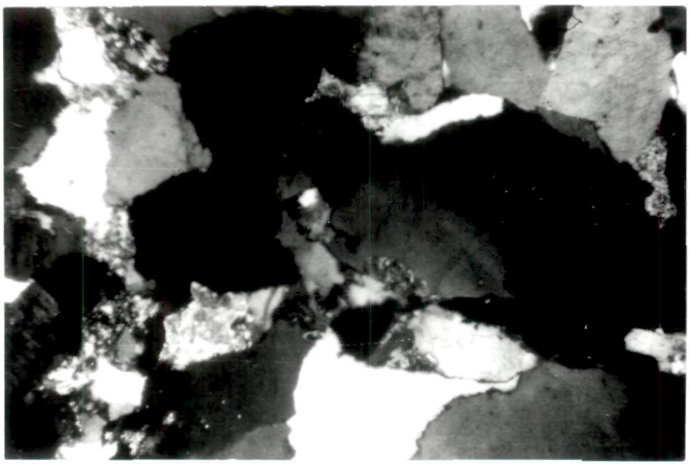

Fig.3

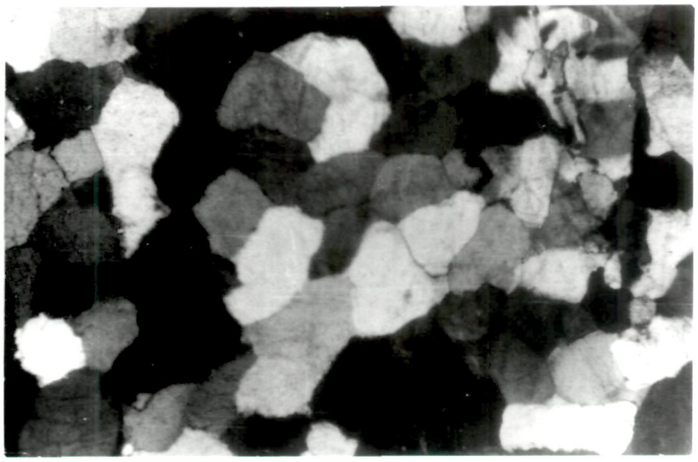

Fig. 4

P L A T E - 23

Fig. 1 Photomicrograph showing rounded zircon in Khori-Malan Sandstone. Crossed nicols; X 400.

Fig. 2 Photomicrograph showing clay as main cementing material in Khardeola Sandstone. Crossed nicols; X 40.

Fig. 3 Photomicrograph showing muscovite in the interspaces of detrital grains in the Khardeola Sandstone. Crossed nicols; X 40.

Fig. 4 Photomicrograph showing long and tangential grain contacts in Khardeola Sandstone. The rock is slightly pressolved and show no evidence of silica cement. Cross nicols, X 40.

almost nothing, 0.46 to 34.23% (average 4.22%) by volume of the rock.

Iron Oxide. - Iron oxide is mainly occurs as thin coating around almost of all detrital constituents of sandstone except those in highly condensed varieties where this coating become discontinuous or almost absent depending upon degree of condensation of the framework constituents. In 8 out of 48 thin sections of sandstones the iron oxide is varies from almost zero, 0.83 to 21.05% (average 7.27%) by volume of the rock. Mostly thin section studies reveals that silica fills the void spaces and forms overgrowth around detrital quartz grains trapping iron oxide rims which outline overgrowth contact (Plate 19, Fig. 2 and Plate 20, Fig. 3). But in some thin sections, it occurs as main cementing matrial (Plate 24, Fig. 1) and whatever little pore space is available is filed by silica.

These relationship show that iron oxide is the first formed cement in the rock followed by silica. The iron oxide cement is perhaps derived from weathering and leaching of the ferro magnesium silicates in source rock.

SANDSTONE CLASSIFICATION

Much work has been done on sandstone classification during the last four decades and the important contributions have been summarised by Klein (1963), Okada (1971), Folk (1980) and Dickinson (1985). Indeed, each classification has practical utility, so long as it is able to define and distinguish sandstone types meaningfully and objectively. Hence, different workers have opted for different classifications depending upon their needs and aims. In the present study, sandstone were classified in two ways: Folk's (1980) classification was employed mainly for the nomenclature and description of sandstones and classification proposed by Dickinson & Suczek (1979) and Dickinson (1985) was used for the interpretation of provenance types.

Classification based on Folk's (1980) scheme. - Folk's (1980) classification of sandstones combined both textural and mineralogical maturity. Folk (1980) used a triangular diagram alloting all types of quartz including metaquartzite (but not chert) to 'quartz' pole, all single feldspars including granite and gneiss fragments to 'feldspar' pole and all other rock fragments plus chert to 'rock fragments' pole, ignoring the percentage to clay matrix, chemically precipitated cements, glauconite, phosphate, fossils, heavy minerals, mica etc. Sandstone were grouped into seven classes: quartzarenite, subarkose, arkose, lithicarkose, sublitharenite, feldspathic litharenite and litharenite. Folk (1980) further proposed daughter triangles for the feldspar pole and the rock fragments pole.

For classifying the studied sandstones, according to Folk's (1980) scheme, all essential constituents were recalculate to 100% ignoring the percentage of clay matrix, chemically precipitated cements, glauconite, phosphates, fossils, heavy minerals, mica flakes etc (Appendix IV). The essential constituents were alloted to one of the three

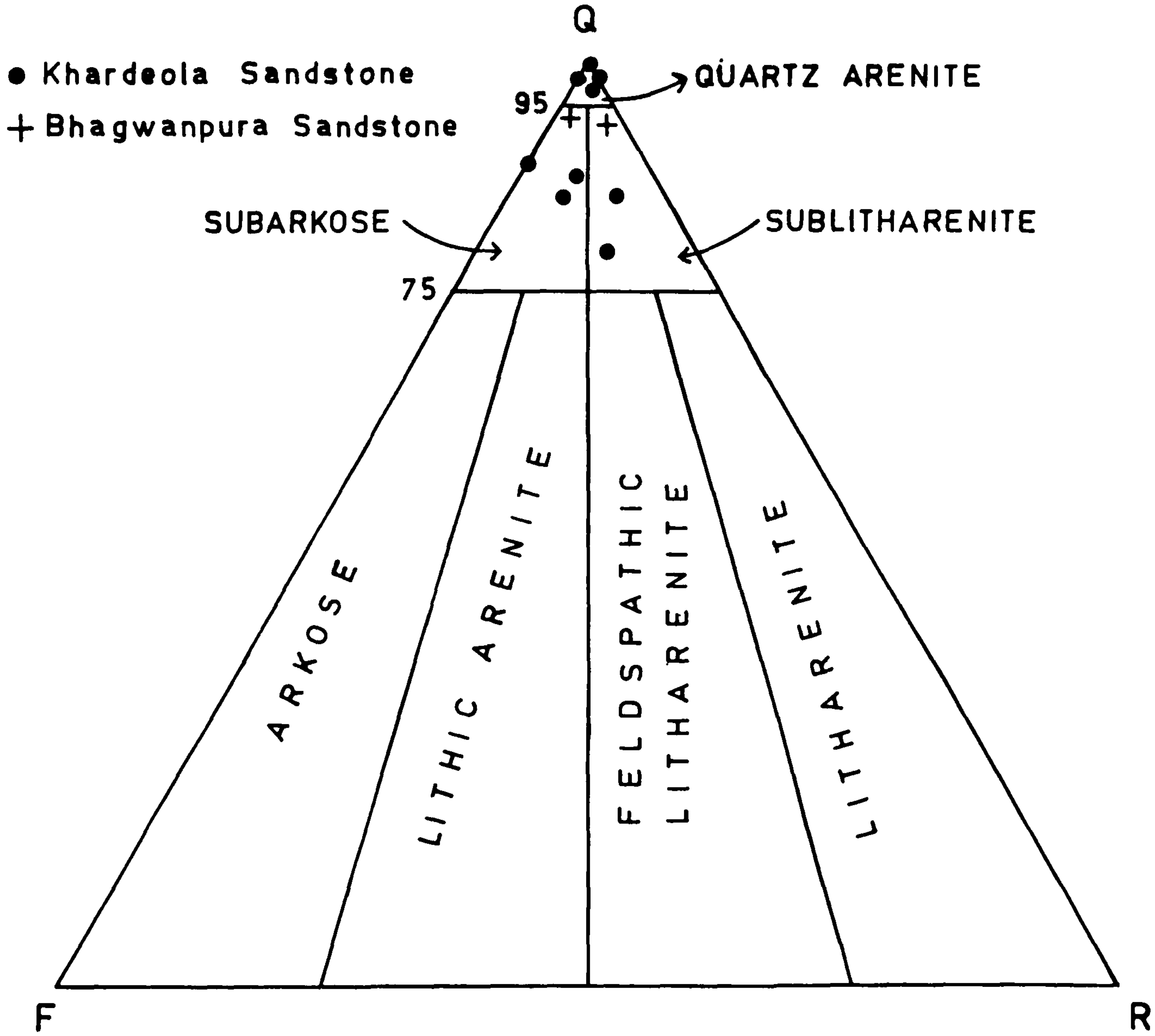

Fig. 19 Part of sandstone classification according to Folk (1980) showing composition of Khardeola and Bhagwanpura Sandstones.

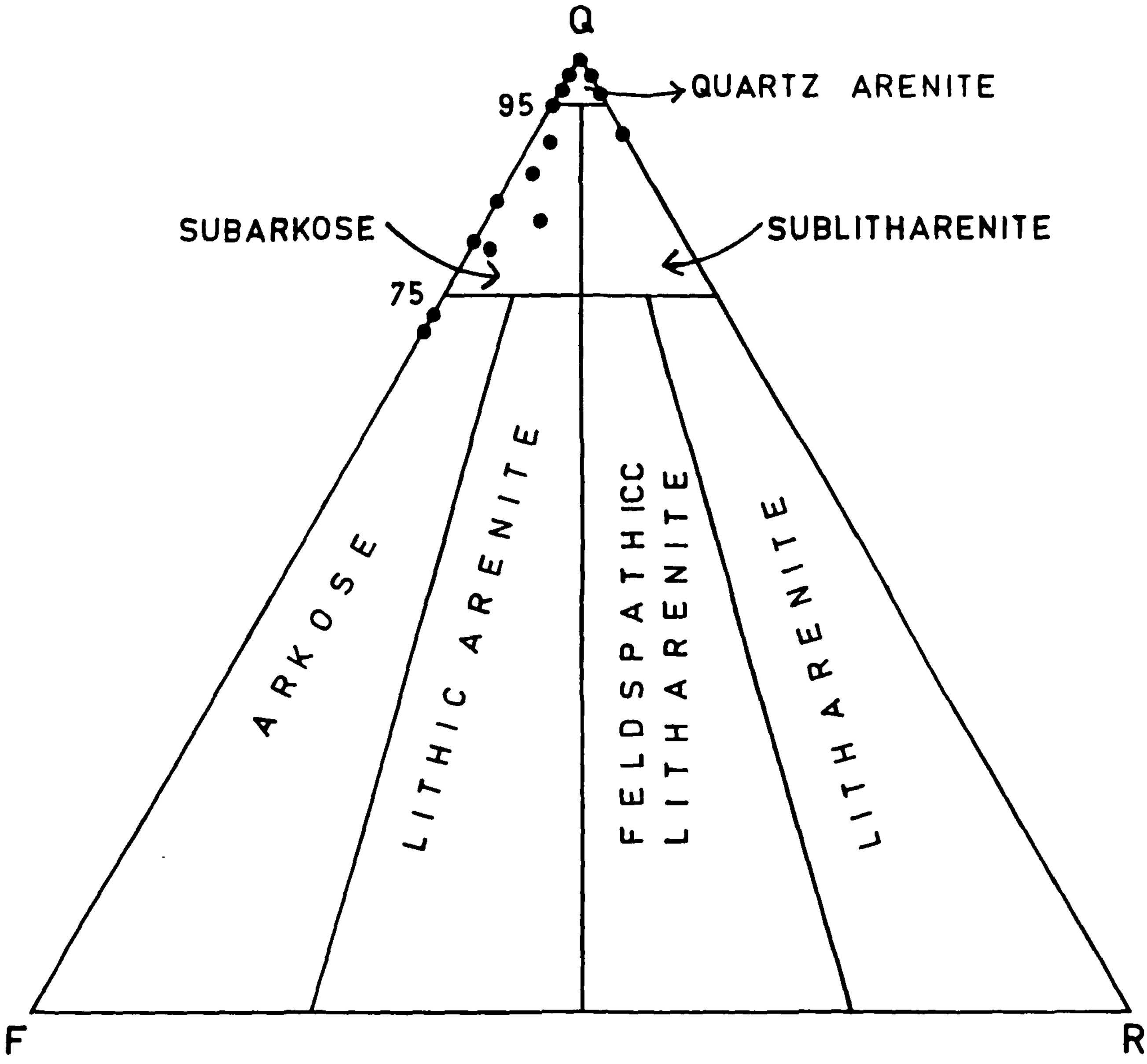

Fig. 20 Part of sandstone classification according to Folk (1980) showing composition of Sawa Sandstone.

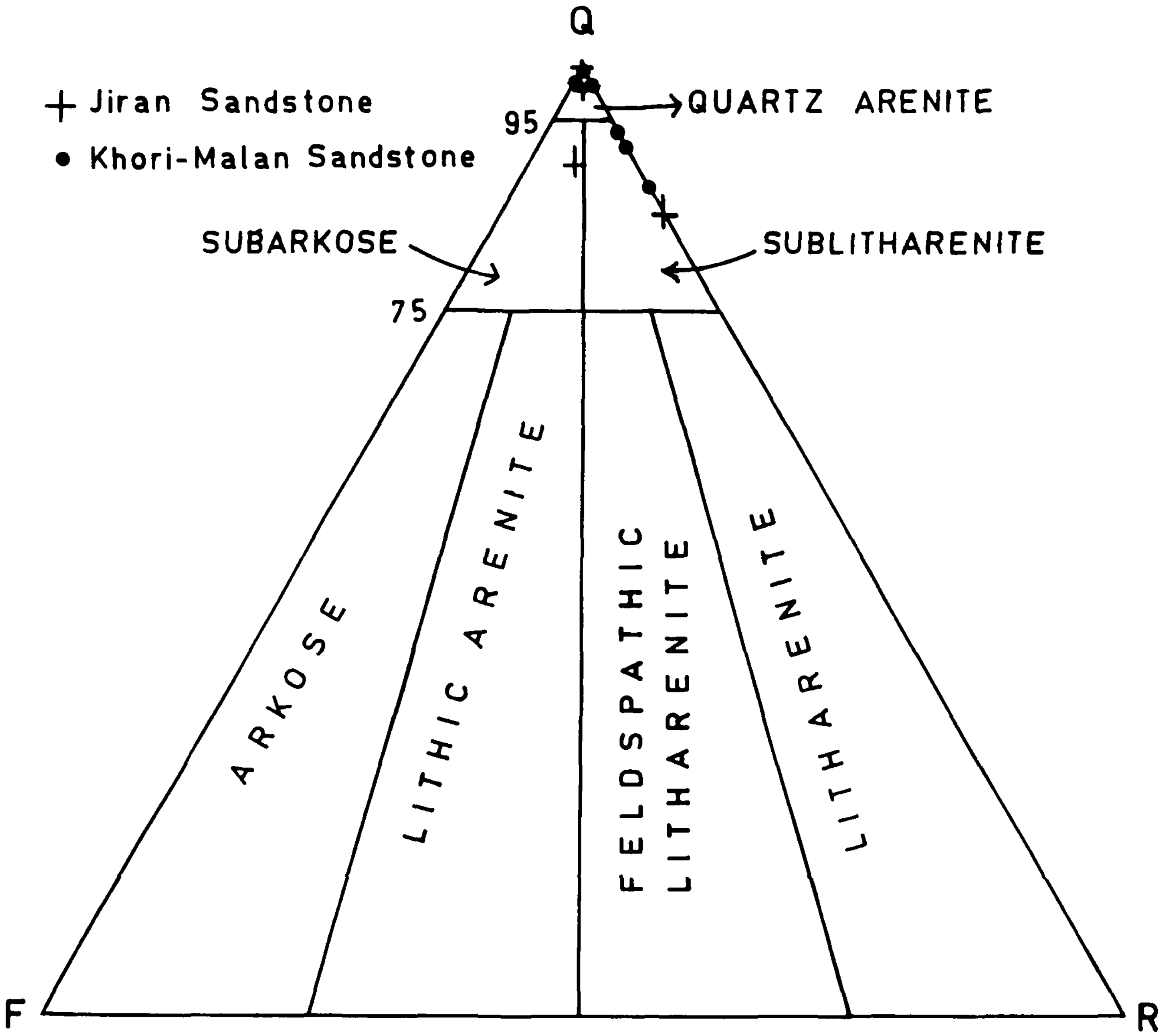

Fig. 21 Part of sandstone classification according to Folk (1980) showing composition of Khori-Malan and Jiran Sandstones.

Table : 7 Classification of Lower Vindhyan sandstone of the study area (after Folk, 1980).

Formation/Member	Quartz arenite	Subar-kose	Subli-thare-nite	Arkose	Total
Khardeola Sandstone	6	3	2	-	11
Bhagwanpura Sandstone	-	1	1	-	2
Sawa Sandstone	6	7	1	2	16
Khori-Malan Sandstone	4	-	5	-	9
Jiran Sandstone	8	1	1	-	10
Total number of 48 Samples analysed	24	12	10	2	48
Percent	50%	25%	21%	4%	

following poles.

Q-Pole : All types of quartz : common quartz, recrystallised metamorphic quartz, stretched metamorphic quartz.

F-Pole : Fresh and altered feldspar plus granite and gneiss fragments.

RF-Pole : All other rock fragments : chert, shale, schist, siltstones, phyllite, limestone, etc.

The studied samples illustrated that : In Khardeola Formation, the sandstone is dominantly quartz arenite followed by subarkose and sublitharenite. In Bhagwanpura Formation, sandstone is subarkose and sublitharenite (Fig. 19). In Sawa Formation, sandstone is subarkose dominant followed by quartz arenite, arkose and sublitharenite (Fig. 20). In Khori-Malan Formation, sandstone is sublitharenite dominantly and followed by quartz arenite. In Jiran Formation, the sandstone is quartz arenite dominantly followed by sublitharenite and subarkose (Fig. 21). In all five formation the sandstone is about 50% quartz arenite, 25% subarkose, 21% sublitharenite and rest 4% arkose (Table - 7).

Classification of Sandstones based on Dickinson's (1985) Scheme. - Dickinson and Suczek (1979) and Dickinson (1985) have emphasized the role of plate tectonics in determining the composition of the sandstone suite at the regional scale. Plate tectonics controls the distribution of different types of sandstones because it governs the key relations between provenance and basin. However, relief, climate, mode of transport and depositional environment can also play important role in determining the sandstone composition.

In the present study, classification of sandstones according to Dickinson's scheme (Table - 8) was attempted and detrital modes were recalculated to 100 percent as the sum of Qm, Qp, P, K, Lv and Ls (Table 9 & Appendix - V). Intrabasinals grains (Zuffa, 1980) was ignored. Heavy minerals are also ignored as they are highly variable as a result of variable response to hydrodynamic and geochemical influences. Similarly, extrabasinal carbonate grains or detrital lime clasts (Lc) are also not considered with other lithic fragments because such grains show vastly different geochemical response during weathering and diagenesis and may be confused easily with intrabasinal carbonate grains (intraclasts, bioclasts, Oolithis, peloids).

For the study of provenance, the present study employed two triangular diagrams : Qt-F-L and Qm-F-Lt (Dickinson, 1985). These two diagrams show compositional fields characteristic of different provenances : Qt-F-L with emphasis on maturity and Qm-F-Lt with emphasis on source rock (Fig. 22 and 23).

Qt-F-L and Qm-F-Lt diagrams may be employed for discrimination of sands derived from various types of provenances in continental blocks, magmatic arcs and recycled orogens. In this context, continental blocks are tectonically consolidated regions composed essentially of amalgamations of ancient orogenic belts that have been eroded to their deep seated roots and lack any relict genetic relief. Magmatic arcs are belts of positive relief composed dominantly of

Table 8 Explanation of recalculated petrographic parameters of sandstone point counts (after Dickinson, 1985)

Qt	=	Qm + Qp
Qt	=	total quartzose grains
Qm	=	monocrystalline quartz grains
Qp	=	polycrystalline quartz grains
F	=	P + K
F	=	total feldspar grains
P	=	plagioclase grains
K	=	Potassium feldspar grains
L	=	Lv + Ls
L	=	total unstable lithic fragments
Lv	=	Volcanic / metavolcanic lithic fragments
Ls	=	sedimentary / metasedimentary lithic fragments
Lt	=	L + Qp

Table - 9 Range and average of percentages of framework modes of the Lower Vindhyan Sandstone (based on Dickinson's 1985 scheme)

	Qt	F	L	Qm	F	Lt	Qp	Lv	Ls	Qm	P	K
					KHARDEOLA SANDSTONE							
Range	81.01-100	0-11.39	0-12.66	46.61-100	0-11.39	0-53.38	0-100	-	2.53-52.65	86.36-100	-	0-13.63
Average	94.12	4.59	1.27	79.94	4.66	15.38	93.86	-	6.13	94.57	-	5.34
					BHAGWANPURA SANDSTONE							
Range	93.44-97.96	2.03-6.55	-	75.5-91.79	2.03-6.55	1.64-22.45	100	-	-	93.33-97.36	-	2.63-6.66
Average	95.7	4.29	-	83.64	4.29	12.04	100	-	-	95.34	-	4.64
					SAWA SANDSTONE							
Range	47.34-100	0-52.65	0-5	23.7-95.6	0-52.65	2.19-53.2	73.22-100	-	0-26.77	31.04-100	0-11.11	0-68.95
Average	82.92	16.32		64.09	15.95	19.94	96.8	-	3.18	78.8	0.69	20.49
					KHORI-MALAN SANDSTONE							
Range	96.64-100	0-1.17	0-3.35	11.17-95.29	0-1.17	3.52-88.22	87.81-100	-	0-12.18	98.78-100	-	0-1.21
Average	99.29	0.13	0.37	64.69	0.13	35.16	98.64	-	1.37	99.86	-	0.13
					JIRAN SANDSTONE							
Range	90.15-100	0-5.62	0-4.21	62.74-100	0-5.62	0-37.25	0-100	-	0-100	94.12-100	-	0-5.87
Average	98.69	0.60	0.7	87.28	0.60	12.10	71.42	-	28.57	99.36	-	4.64

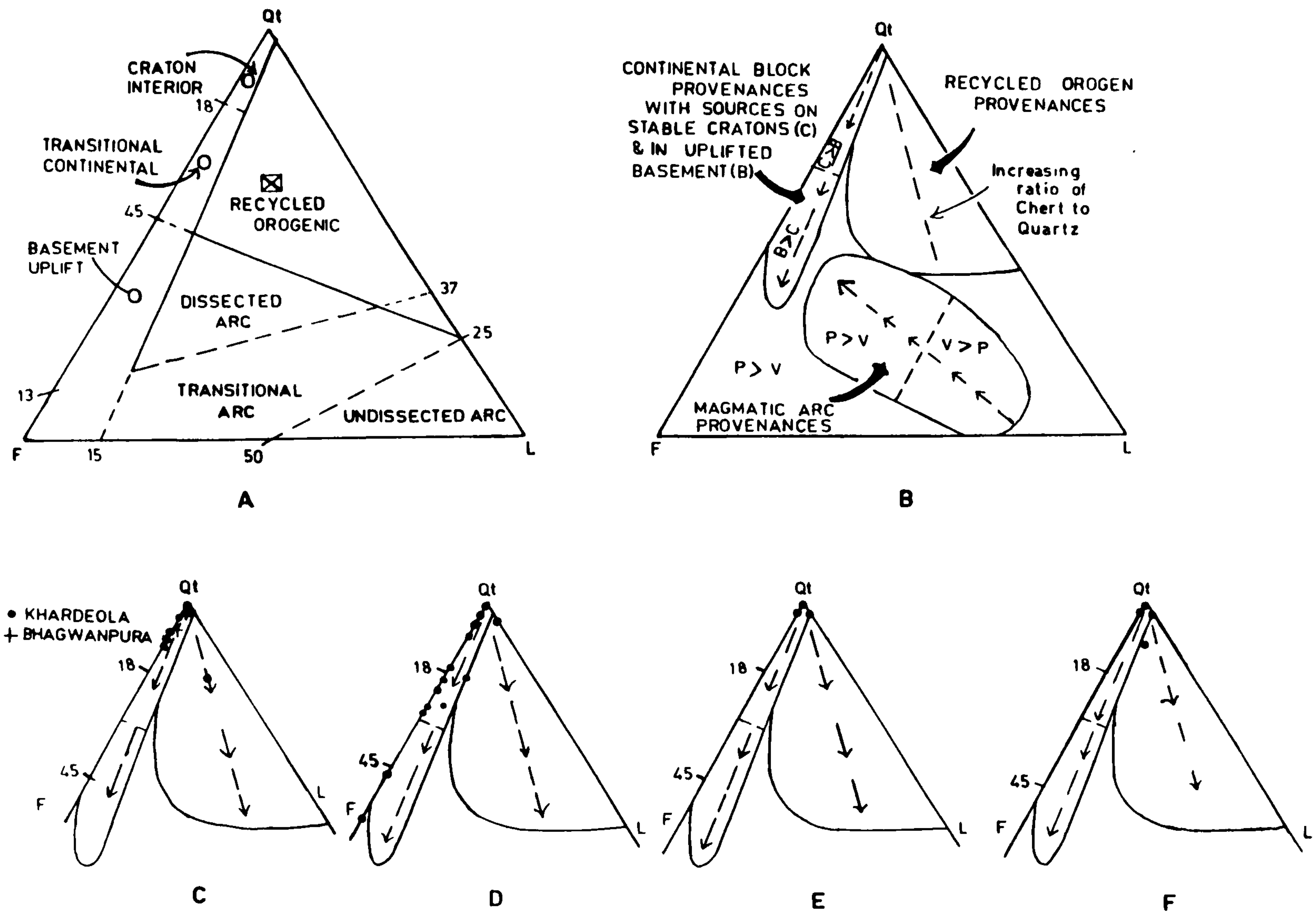

Fig.22 Classification of Lower Vindhyan Sandstone of the study area according to Dickinson's(1985) scheme (A and B). C. Plot of samples from Khardeola and Bhagwanpura Sandstone. D. Plot of samples from Sawa Sandstone. E- Plot of samples from Khori-Malan Sandstone. F. Plot of samples from Jiran Sandstone.

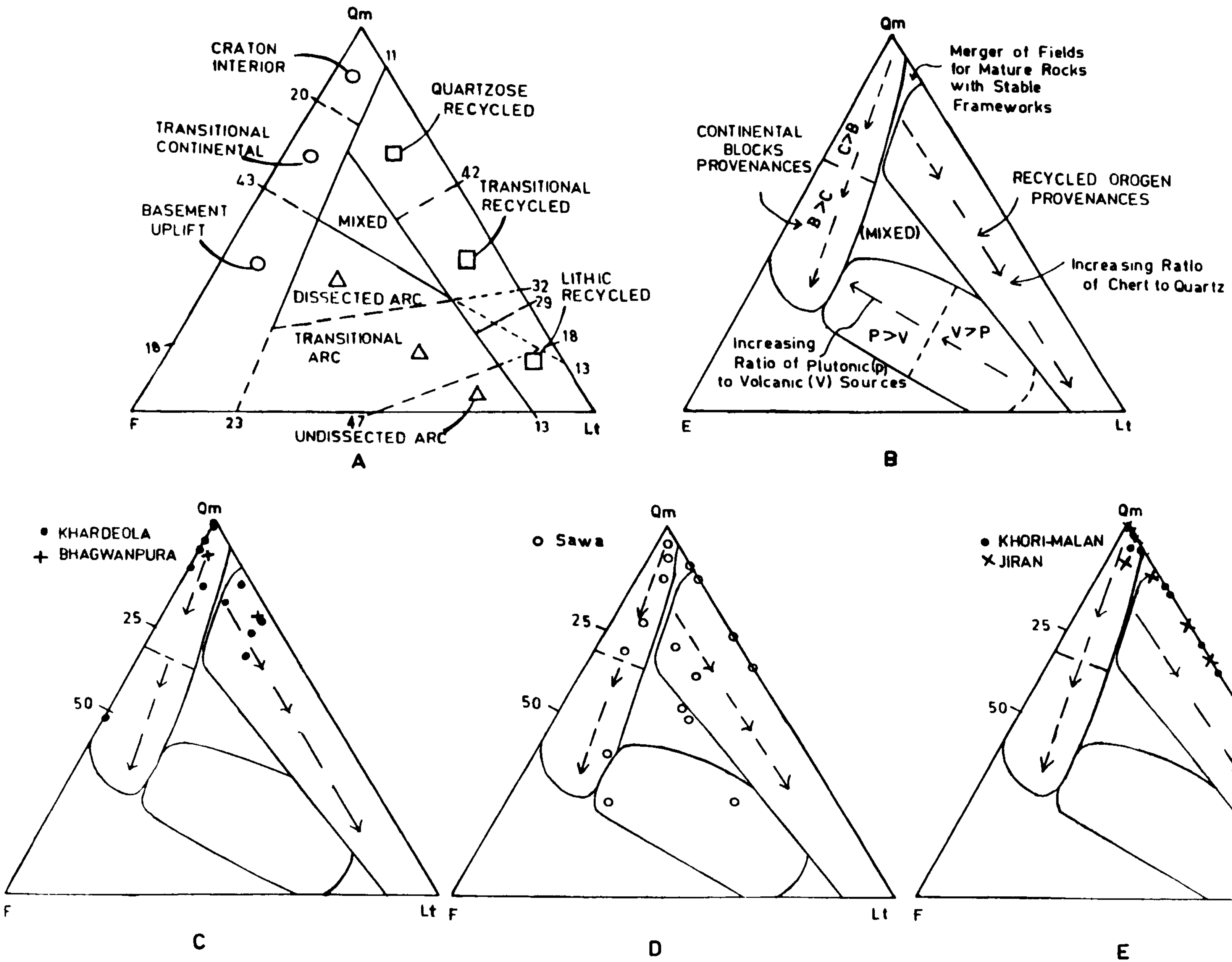

Fig. 23 Classification of Lower Vindhyan Sandstone of the study area according to Dickinson's (1985) scheme (A and B). C. Plot of samples from Khardeola and Bhagwanpura Sandstones. D. Plot of samples from Sawa Sandstone. E. Plot of samples from Khori-Malan and Jiran Sandstones.

penecontemporaneous association of orogenic volcanic and plutonic igneous rocks, together with associated metamorphic wall rocks, produced by continuing subduction along arc-trench system. Recycled orogens include the deformed and uplifted supracrustal strata, dominantly sedimentary but also volcanic in part, exposed in varied fold thrust belts of orogenic regions.

On the Qt-F-L plots, about 93% of the studied samples lie in the craton interior field and rest 7% in recycled orogen field (Fig. 22, C-F). On the Qm-F-Lt plots 40% of the studied samples lie in the craton interior field, 49% fall in the quartzose recycled field and rest 11% lie in the mixed, dissected and transitional arc field (Fig. 23, C-E).

INTERPRETATION OF PROVENANCE

The average percentage of Qt-F-L modes are Qt 94.12, F 4.59, L 1.27 in Khardeola Sandstone; Qt 95.7, F 16.32, L 0.75 in Sawa Sandstone; Qt 99.29, F 0.13, L 0.37 in Khori-Malan Sandstone and Qt 98.69, F 0.60, L 0.7 in Jiran Sandstone (Table - 9). These average modal composition of studied sandstones calculated on the Qt-F-L plots of Dickinson scheme (1985) are comparable to those sandstones described from many other cratonal cover sequences e.g. the Western North Atlantic Quaternary (Hubert and Neal, 1967), the Pleistocene Turbidites of Canada basin (campbell and clark, 1977), the cretaceous - Tertiary deposits of Middle Mississippi valley (Potter and Pryor, 1961), the carboniferous unit of the eastern interior coal basin (Potter and Pryor, 1961) and the Precambrian

Formation of central Virginia (Schwab, 1971). These sedimentary rocks have been interpreted to represent especially mature detritus that accumulated within platform successions or interior basins of the continental blocks (Dickinson and Suczek, 1979).

The main sources for craton derived quartzose sand are low lying granite and gneissic exposure of the shield areas supplemented by recycling of associated flat-lying platform sediments (Dickinson and Suczek, 1979). High quartz contents and high ratios of K - feldspar to Plagioclase reflect intense weathering on craton with low relief and/or prolonged transport across continental surfaces having low gradients. Essentially pure quartz sands, as those of the Khori-Malan and Jiran Formations, represent especially mature detritus that accumulates with in platform successions or interior basins of the continental blocks.

The average percentage of Qm-F-Lt modes are Qm 79.94, F 4.66, Lt 15.38 in Khardeola sandstone; Qm 83.64, F 4.29, Lt 12.04 in Bhagwanpura Sandstone; Qm 64.09, F 15.95, Lt 19.94 in Sawa Sandstone; Qm 64.69, F 0.13, Lt 35.16 in Khori-Malan Sandstone and Qm 87.28, F 0.60 and Lt 12.10 in Jiran Sandstone (Table - 9). These mean modal composition of studied sandstones are comparable to those sandstones described from Apennine Eocene of Italy (Sestini, 1970); Carboniferous lithic sandstones of Ouachita mountains, Arkansas (Graham et al, 1976); Ordovician Plynlimon Group of west central Wales (James, 1971); Western-North Atlantic Quaternary of Western subprovince (Hubert and Neal, 1967) and Pleistocene turbidites of Canada basin, Arctic ocean (campbell and clark, 1977). All these ancient and recent examples are interpreted to represent craton interior and recycled orogen provenance.

Among the five formations, sandstones of Khardeola, Bhagwanpura and Jiran show the maximum mineralogical maturity followed by the sandstones of the Khori-Malan and Sawa which show slightly less mineralogical maturity.

Thus Qt-F-L and Qm-F-Lt plots of four sandstones (Khardeola, Bhagwanpura, Khori-Malan and Jiran formations) shows that they were derived from a stable craton and partly from recycled orogen provenances. However, a marked variation towards mineralogical immaturity is seen in the Sawa Sandstones which were mainly derived from recycled orogen provenance.

DIAGENESIS

The term "diagenesis" has been used rather loosely in geological literature, but all writers agree that it is a postdepositional process which tends to modify the primary characters of the sediments. The term "diagenesis" includes all changes taking place in a sediment between deposition and metamorphism but excludes all weathering processes (Correns, 1939; Blatt, 1966; Fuchtbauer, 1967 a). However, there exists no sharp boundary line which seperates diagenesis from metamorphism. Pettijohn et al (1987, P. 425) defined diagenesis as "a process of chemical and physical changes of sediments upto the lowest grade of metamorphism" also called "anclimetamorphism (Fuchtabauer, 1974, P. 155). Diagenesis starts from the deposition of sediments and it modified the shape, texture as well as the composition of the sediment under compaction . No attempt has been made or said about the diagenesis of Middle Proterozoic Lower Vindhyan rocks of south eastern Rajasthan. Based on petrographic study alone, the diagenesis of Lower Vindhyan rocks of study area is carried out and indicated by the occurrence of different types of cement, matrix, their interaction with detrital constituents and presence of detrital mica.

Silica, clay matrix, iron oxide and carbonate in order of abundance occur in Khardeola, Bhagwanpura, Sawa, Khori-Malan and Jiran sandstone. On the basis of the inclusions and sequence of replacement of one cement by another, it is possible to suggest that authigenic quartz is the oldest cements succeeded by the iron oxide, clay and carbonate replaces all the other cementing materials.

The origin of cement has always been an interesting problem ever since the geologists and petrographers became aware of their presence in sedimentary rocks. Van Hise (1904) stated that the cementing material may be dissolved in zone of weathering and redeposited in sands as cement. The meteoric or artesian water is supposed to be an important source of cementing material in sandstone (Pettijohn, 1984). Johnson (1920) supposed that the connate water of shale which squeezed out due to compaction could deposit silica in available pore spaces of interbedded sandstones. It is believed by many workers that silica solutions may be generated from within the strata either by the interpenetration and pressure solution of quartz grains during burial and/or tectonic movements (Waldschmidt, 1941; Gilbert, 1949; Taylor, 1950; Heald, 1953, 1955, 1956; Thompson, 1959) or by the solution of interstitial fines (Pye, 1944, Goldstein, 1948). The conversion of montmorillonite to illite supplies dissolved silica (Pettijohn, et al, 1987) just as Kaolinisation of feldspars releases silica in solution to be reprecipitated, in the pore spaces (Segonzac et al, 1970; Fuchtbauer, 1974). Replacement of silicate minerals by carbonates is also thought to be contributory source of silica (Walker, 1960).

As mentioned elsewhere, in thin section study of the Lower Vindhyan Sandstones provides undeniable evidence that pressure soluation was a major factor in cementation. Many thin sections show interpenetration of quartz grains on a large scale and most specimens studied are pressolved to varying degree. Although no quantitative evaluation of the degree of interpenetration of grains in the different sandstone formations was made, a rough visual estimate shows that the Khardeola Sandstone is more highly pressolved than the Sawa, Khori-Malan and Jiran Sendstones. In view of the closely comparable mineralogy and identical deformation history of all the sandstone formations in the area, the most plausible explanation for the difference in the degree of condensation of their framework, appears to be that the Khardeola, due to its deeper burial, was more prone to pressure solution as compared to the other three formations.

It is also possible that dissolved silica, derived from source area due to weathering of silicate rocks i.e. granite, metaquartzite, quartz schist & chert beds etc. belonging to the Berach granite & Bhadesar quartzite might have come in solution with the tidal or longshore or Rip channel currents which deposited Lower Vindhyan rocks and redeposited in pore spaces. The petrographic study of Khardeola, Bhagwanpura, Sawa, Khori-Malan and Jiran Sandstones reveals that feldspar are widely replaced by clay (Plate 19, Fig. 3 and Plate 21, Fig. 3) and part of silica in sandstones may have been so derived. Iron in these sediments may have come in solution derived from the source rock due to weathering of ferromagnesium silicate, and was precipitated in pore spaces due to oxidation in the depositional basin. The carbonate cement is scarely distributed and is probably youngest in age. Artesian water containing dissolved carbonate is thought to be the chief source of carbonate cement in continental sediments (Pettijohn, 1975). It is believed that authigenic kaolinite may have been produced by the process of replacement of K - feldspar after decomposition by substratal water at shallow burial state (Fuchtbauer, 1974, P. 145). The detrital mica (muscovate is occasionally deformed or bent (Plate 23, Fig. 3) in the interspaces of detrital grains. This may be due to the differential overloading or compaction of the sediments after the deposition.

MATRIX

Three varieties of interstitional matrix are recognised on the basis of its occurrence, colour and relation with framework constituents (Dickinson, 1970).

Orthomatrix. - Recrystallized material; it is fine grained, granular, structureless, pale brown and forms tangential coating on detrital grains (Plate 21, Fig. 4).

Pseudomatrix. - Deformed and squashed lithic fragments, brown in colour, coarser than orthomatrix, having corroded contacts with detrital grains & occupies large pore spaces wherever available (Plate 23, Fig. 2).

Epimatrix. - Diagenetic product of alternation of clay, white and cream coloured, forming dense mesh between pore spaces, locally appears as small booklets replacing feldspar (Plate 19, Fig. 3).

PETROGRAPHY OF LIMESTONE

Introduction. - Petrographic study under microscope is the most important part of the investigations of carbonate rocks. Petrography helps in the interpretation of the depositional environments. The concept of depositional interpretation of microfacies i.e. petrographic study was evolved by Cuvillier and schurmann (1951-1969). An excellent review of the importance of the concept was published by Fairbridge (1954). The early work on carbonate microfacies employed mainly Paleontological criteria. Flugel (1972) added sedimentological criteria to the basic paleontological approach and described several basic types of microfacies. Excellent illustrations of some of the basic microfacies were given by Horowitz and Potter (1971).

A very little contribution to petrography of Lower Vindhyan Limestone of south east Rajasthan has been made so far. A few authors such as Heron (1936), Coulson (1927) and Prasad (1984), however, have paid less attention about petrography of the limestone of the studied area. Therefore present petrographic study deals with textural and compositional characteristics of carbonate rocks.

Methodology. - In the present study, 36 samples selected for study of texture and composition of limestone. 19 and 17 samples were selected from the Bhagwanpura and Nimbahera Limestone respectively. These samples were selected in such a to cover uniformly both laterally and vertically the out crops of the two formations. Petrographic studies were mainly concerned with textural and compositional characteristics of the carbonate rocks. Calcite and dolomite were differentiated by staining with Alizarin Red S (Friedman, 1959).

MAJOR PETROGRAPHIC CONSTITUENTS

The terminology and classification proposed by Folk (1980) have been employed here. The main petrographic constituents of the carbonate rocks under study are intraclast, sparry calcite cement, micrite and dolomite. Terrigeneous admixture such as detrital quartz, quartzite, chert, feldspar and calcite grain are present in most of the samples.

Intraclasts. - Folk (1980, P. 157) defined 'intraclast' as a fragment of penecontemporaneous, generally weakly consolidated carbonate sediment that has been eroded from adjoining parts of the Sea bottom and redeposited to form a new sediment. Intraclasts in the study area are rounded with firm boundaries. They are composed of lithologies similar to the microfacies of the study area suggesting their origin by penecontemporaneous origin.

Sparry calcite. - According to Folk (1980, P.156) sparry calcite generally forms grains or crystals of 10 micron or more in diameter and is distinguished from microcrystalline calcite by its clarity as well as coarser crystal size. Bathurst (1971, P. 417, 419) distinguished sparry calcite by the inter crystalline boundaries in the sparry mosaic which are made up of plane interfaces and characterized by enfacial junctions. In the studied carbonate rocks, sparry calcite occurs predominantly as interparticle pore filling cement. Interparticle pore filling sparry calcite cement is of granular type (Orme & Brown, 1963).

Micrite. - Micrite is microcrystalline carbonate material which is finer than 0.004mm or 4 microns (Folk, 1980). The upper size limit of micrite particles was fixed at 31 microns by Leighton and Pendexter (1962) and at 50 microns by Bissell and Chillingar (1967). In the carbonate rocks under study carbonate material finer than 0.031 mm has been termed micrite, as suggested by Leighton and Pendexter (1962). The micrite has occasionally recrystallized to 'pseudospar' which consists of grains more than 30 microns in diameter (Folk, 1965).

Dolomite. - Dolomite occurs in various thin section either as single anhedral to subhedral crystals floting in micrite or in the form of xenotopic to hypidiotopic crystal aggregates forming layers and patches within micrite. The dolomite is originated from replacement of micrite is evidenced by several features of the crystals, such as zoning (Murray, 1964), inclusions of micrite (Carozzi, 1960, P. 282) and their floating nature (Carozzi, 1960, P. 282, Textoris, 1968, P.231).

DESCRIPTION OF MICROFACIES

A total of 4 microfacies were recognized in the study area. Dunham's (1962) and Folk's (1980) classificatory schemes were followed for the classification of microfacies.

Micrite

Micrite occurs in lithofacies A, D and E of Bhagwanpura and Nimbahera Limestone as pale blusish grey to dark grey micritic limestone. It consists of a homogeneous and structureless aggregate of microcrystalline calcite grains and some silt size quartz, chert and feldspar grains which are sparsely distributed. The detrital quartz is angular to subrounded (Plate 24, Fig. 2). As the rock has no allochem material and no sparry calcite. This implies both a rapid rate of formation of microcrystalline Ooze together with lack of strong currents. Micrite mostly forms in areas of ineffective winnowing and calm waters of low energy like protected lagoons, broad platforms or in moderately deep waters (Folk, 1980). Abundance of micrite in this microfacies indicates lack

PLATE 24

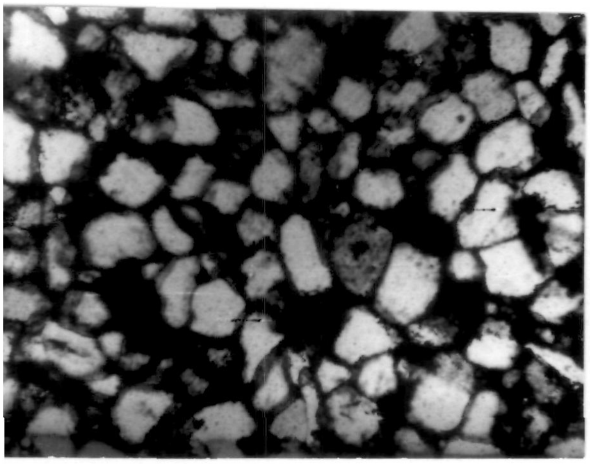

Fig. 1

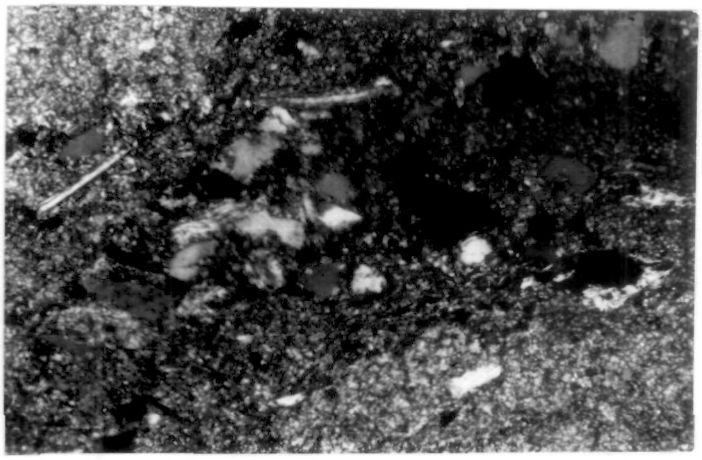

Fig. 2

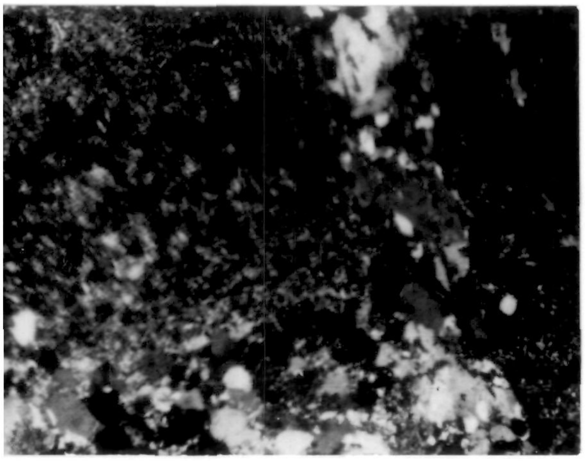

Fig. 3

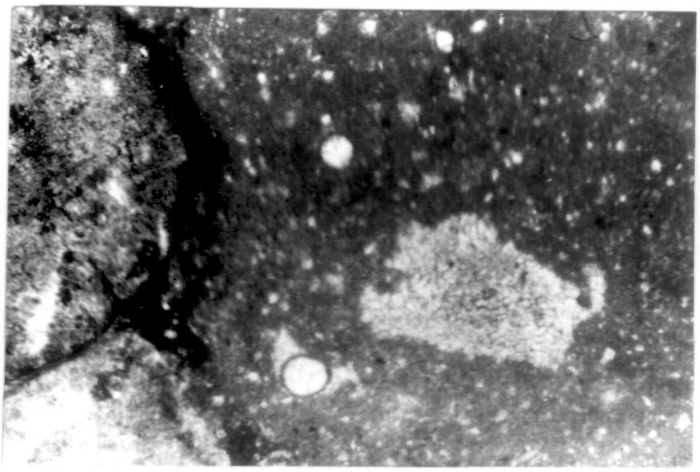

Fig. 4

P L A T E - 24

Fig. 1 Photomicrograph showing iron oxide as main cementing material in Khori-Malan Sandstone. Plane polarized light; X 100.

Fig. 2 Photomicrograph of micrite from lithofacies 'A', 'D' and 'E' showing admixture of subangular to angular detrital quartz grains, Nimbahera Limestone. Crossed nicols; X 100.

Fig. 3 Photomicrograph of stromatolitic Bhagwanpura Limestone from lithofacies 'C' showing micrite with terrigenous admixture of silt size quartz grains crossed nicols; X 40.

Fig. 4 Photomicrograph of silty micrite from lithofacies 'B', 'C' and 'D' showing bird's eye structures filled with sparry calcite, Bhagwanpura Limestone. Plane Polarized light; X 40.

of persistent and strong currents or waves and low energy conditions of the environment of deposition. Micrite is mainly formed in shallow sheltered lagoonal areas or on broad, submerged shelves of little relief and moderate depth where wave action is cut off by the very width of the shelf. Some micrite may also form in deeper offshore areas.

Silty Micrite

Silty micrite occurs in lithofacies B, C and D of Bhagwanpura and Nimbahera Limestone, as pink, argillaceous micritic limestone. It is composed entirely of micrite with about 10% terrigeneous admixture by volume (Plate 24, Fig. 3). The terrigeneous constituents are silt size quartz, chert and minute mica flakes. Some thin sections show abundant horizontal fenestrae and bird's eye structure filled with sparry calcite (Plate 24, Fig. 4). Fenestrae or bird's eye is a primary or penecontemporary gap in rock framework (Shinn, 1983). Bird's eyes and fenestrae structure in silty carbonates are most commonly indicative of upper intertidal to supratidal environments (Wolf, 1965; Shinn et al, 1969; Shinn, 1983). Abundance of terrigeneous material reflects a sudden influx of clastic material.

Intramicrite

Intramicrite occuring in lithofacies C of Bhagwanpura Limestone. It consists of intraclast of micrite with some detrital quartz grains. The intraclast are mostly elongate with rounded edges, some are equant and a few angular. They

PLATE 25

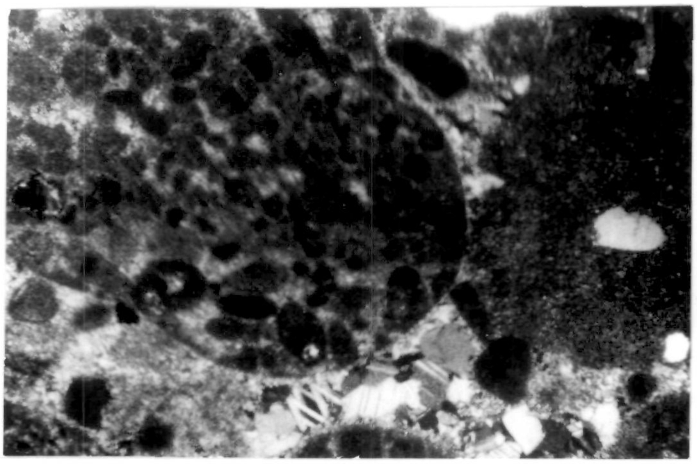

Fig.1

Fig.2

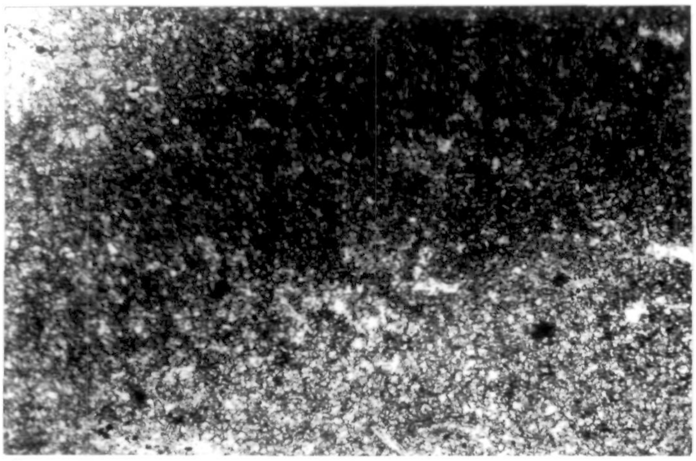

Fig. 3

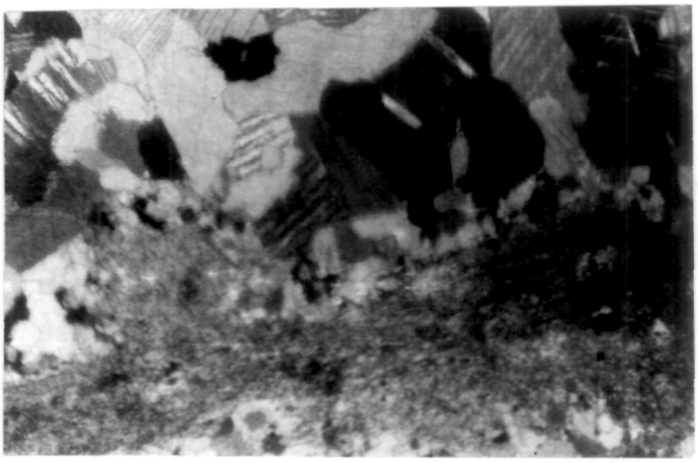

Fig.4

P L A T E - 25

Fig. 1 Photomicrograph of intramicrite from lithofacies 'C' showing rounded peloid composed of micrite with terrigeneous admixture of silt size quartz, calcite and feldspar grains. Bhagwanpura Limestone. Cross nicols; X 40.

Fig. 2 Photomicrograph of dolomitized micrite from lithofacies 'C' showing minute crystal of dolomite with terrigeneous admixture of silt size quartz, chert and feldspar. Bhagwanpura Limestone. Crossed nicols; X 100.

Fig. 3 Photomicrograph of lithofacies 'E' of Nimbahera Limestone showing aphenocrystalline micritic and dolomitized micrite with very fine chert grains. Plane poarized light; X 100.

Fig. 4 Photomicrograph of lithofacies 'C' of Bhagwanpura Limestone showing alternate laminae of micrite and rhombic dolomite crystal with admixture of sand size quartz, chert and calcite grains. Crossed nicols; X 40.

are well sorted and some what loosely packed. The intraclast is composed of micrite and dolomitized micrite with terrigeneous admixture (Plate 25, Fig. 1). The matrix is consist of peloidal micrite, opaque to quartz rich translucent micrite and patches of dolomitized micrite. The terrigeneous material are sand size quartz, calcite grain, recrystallized quartz with minute mica flakes. Detrital quartz grain is subrounded to subangular but some angular grain are occasionally occur. It appears that intraclasts have been derived locally because their composition is similar to that of the matrix. Both intraclasts and matrix are composed of small, rounded or elliptical peloidal intraclast cemented together with sparry calcite (Plate 25, Fig. 1). The identical composition mostly of the intraclast and matrix strongly suggests that the intraclast were generated by high energy currents which ripped up from the ancient channel bed. Thus it is evident that most of the intraclast originated within the channel by current action and were redeposited there.

Dolomitized micrite

The microfacies occurs in lithofacies B & C of the Bhagwanpura Limestone. The dominant constituents of the microfacies are dolomite, terrigeneous admixture and sparry calcite. The microfacies shows extensive dolomitization and recrystallization. Dolomite occurs mostly as patches. Single floating crystals in micrite occurs rarely. The dolomitized patches consist of very minute crystal in the Centre where as outwards the size of the crystals increases to medium crystalline (Plate 25, Fig. 2). Some dolomitized patches consist of aphenocrystalline dolomite in which rhombic shape is not discernible. The floating crystals of dolomite are very finely crystalline (Plate 25, Fig. 3). The buff colour & zoning of dolomite crystals is due to increase in iron content. Remnant micrite occurs in the centre of some dolomite crystals.

Terrigeneous admixture includes fine sand and silt size grains of quartz, feldspar, chert, muscovite and opaques (Plate 25, Fig. 4). The grains are subangular to subrounded with corroded boundaries. The microfacies was originally deposited as micritic limestone which as a result of dolomitization and recrystallization has lost much of its original texture. Gebelein and Hoffman (1971) has described that magnesium concentration for dolomite is provided by algal filaments.

CHAPTER V

PALEOFLOW ANALYSIS

Introduction. - Paleocurrent studies have received a great deal of attention by sedimentologists during the last three decades or so because of their increasing importance in basin analysis.

The art of Paleocurrent analysis was invented by nineteenth century English amateur, Henry Clifton Sorby, who published his first paper on the subject in 1853. Rubey and Bass (1925) got the first credit to have actually plotted cross bedding measurements on a map. Brinkmann (1933) was, perhaps the first of the modern workers to have a clear concept of objectives of Paleocurrent research. A new interest was created after Potter and Olson (1954). They used the cross bedding as a tool for determination of Paleocurrent. Mckee (1940), Olson and Potter (1954), Tanner (1955), Pettijohn (1957b) and his students (Pelletier, 1958; McBride, 1962), Hamblin (1958), Wurster (1958) and others are among the Pioneer workers of the paleocurrent study. In recent years Potter and Pettijohn (1963, 1977), Smith (1972), Picard and High (1973), Mckee (1966), Bigarella (1970, 1971), Klein (1970a)and Miall (1976, 1984b,P. 256) have given detailed and critical accounts of this method. In India, paleocurrent studies have been undertaken in considerable details during the past three decade particularly on Proterozoic Vindhyan sequence of Vindhyan basin (Akhtar, 1978; Banerjee and Sengupta, 1963; Banerjee & Singh, 1981; Bhardwaj & Mathur, 1989; Jafar et al, 1966; Lahri, 1964; Mishra, 1967; Srivastava

& Bhardwaj, 1978).

However, the Lower Vindhyan rocks of southeastern Rajasthan have not been adequately studied so far. Preliminary work by Prasad (1984), based on sporadic measurements, yielded local paleocurrent directions of the sandstone towards east. It was therefore most appropriate that a well designed extensive work should be undertaken to determine paleocurrent of Lower Vindhyan rocks of southeastern Rajasthan. The proposed study aims at determining the paleoflow direction of formations constituting the Lower Vindhyan sequence, outcropping over an area of about 675 Sq.Km. The study attempts to evaluate the following aspects of sediment transport and depositional agency in relation to the various stratigraphic formations as recognised in the Lower Vindhyan sequence of rocks as described to earlier :

(1) Paleoflow direction through space and time,

(2) Paleoslope

(3) Location and composition of Provenance - which will be described in next chapter.

Method of Study and Data Processing. - Directional data for this study comprise foresetdip azimuths for both planar and trough cross-bedding. For trough cross bed azimuth, a hierarchichal sampling plan (modified after Potter and Olson, 1954, Potter and Pettijohn, 1977) was followed. Thus, the area divided into increasing sampling size from locality, sector and formation level. Planar cross bed azimuth is very scare in studied rocks and due to paucity of data, no sectorial subdivisions were possible and the entire area covered by them was taken at locality and formation level.

The methods of measurement of planar cross-bed dip azimuths varied from outcrop to outcrop depending upon the nature of exposures. At outcrops where the foreset planes were exposed, the dip azimuths were measured directly with the Brunton compass. Biplanar method of Potter and Pettijohn (1977, P. 99) was followed on outcrops where a suitable single surface of planar foreset was not exposed in vertical sections (a-c plane). Trough foreset selected for measurements were those exposed in crescentric outline on vertical sections (a-c plane) as well as on bedding surface (a-b plane). In the case of bedding surface (a-b plane), the azimuth of the acute bisectrix of curved surfaces was taken as the true azimuth of the dip of foreset surfaces of the trough cross bed.

The sampling pattern adopted for cross bed dip azimuth study is not based on any predetermined system, because no paleocurrent study was ever undertaken in this area which could provide guidelines for spacing the observation points. All accessible outcrops were examined and about 6-16 readings from cross bedded units were recorded at each locality depending upon the local variability of foreset azimuth as per sampling plan. The spacing between different outcrops was determined largely by the availability and accessibility of suitable outcrops. However, care was taken to cover the strata both vertically and laterally as far as possible within the available means.

The paleocurrent study is based on 1310 readings spread over 121 localities of Lower Vindhyan rock; their formation wise break-up is given in Appendix-VI and Table 10. About half localities where the structural dips exceed 25° the foreset dip azimuth was corrected for the tilt by rotating the poles of foreset planes on Schmidt Stereonet (Appendix-VII) (Potter and Pettijohn, 1977, P. 371).

Paleoflow Results and Interpretation. - The foreset dip azimuthal data were calculated both graphically (rose diagrams) and statistically (Potter and Pettijohn, 1977, P.98) at locality, sector and formation level separately for trough and planar cross bedding, as and where developed in each formation. However, for planar cross bedding , the data calculated at locality and formation level only due to lack of data. The cross bedding azimuths were grouped in 30° class intervals for constructing the rose diagram (Lindholm, 1987). The statistical parameters : Vector mean (θv), Vector magnitude in percent (L), standard deviation (S) and variance (S^2) were calculated according to vector Summation method (Curray, 1956) at locality and sector and formation level for Khardeola, Sawa, Khori-Malan and Jiran Sandstones. Standard deviation and variance were not calculated at locality level owing to small number of azimuth. The results are recorded in Table - 10 for data at locality and in Table - 11 for those at sector and formation level respectively for Khardeola, Sawa, Khori-Malan and Jiran Sandstones. The distribution of foreset dip azimuths were shown as rose diagrams respectively for

Table - 10 Locality level values of Vector Mean (θv) and Vector Magnitude (L%) for Khardeola, Sawa, Khori-Malan and Jiran Cross-bedded Sandstone.

Locality Number	Number of Readings (N)	θv (in degree)	L%
KHARDEOLA SANDSTONE			
Trough Cross-bedding			
1	8	205	72.72
2	8	129	84.64
3	12	156	92.79
4	12	160	93.67
5	8	95	72.73
6	10	96	47.88
7	10	110	82.28
8	12	110	98.11
9	8	328	54.79
10	12	343	66.11
11	8	116	96.80
Planar Cross-bedding			
A	5	159	97.83
B	5	158.4	87.16
C	8	98	97.45
D	6	125	96.97
E	6	124	88.18
F	6	131	80.73
SAWA SANDSTONE			
Trough Cross-bedding			
12	10	195	14.64
13	8	165	93.29
14	8	203	90.81
15	6	204	79.80
16	10	159	92.49

Locality Number	Number of Readings (N)	θv (in degree)	L%
17	6	305	97.00
18	8	51	84.64
19	8	158	77.98
20	8	150	96.59
21	6	9	41.30
22	26	143	59.85
23	28	164.5	75.44
24	6	42	74.54
25	12	141	77.09
26	12	156	92.79
27	8	195	93.30
28	8	315	87.00
29	8	347	80.86
30	8	345	100.00
31	8	75	24.99
32	8	45	100.00
33	10	33	96.73
34	18	191	62.73
35	20	225	20.00
36	8	142	97.45
37	8	112	77.99
38	8	135	25.00
39	14	192	35.76
40	14	206	37.80
41	4	150	96.60
42	9	86	88.19
43	9	315	33.33
44	6	205	97.00
45	12	205	78.86
46	18	255	19.24
47	14	125	79.35

Locality Number	Number of Readings (N)	θv (in degree)	L%
	Planar Cross-bedding		
G	10	153	96.72
H	10	207	96.72
I	11	215	87.46
J	10	213	86.39
K	8	26	90.35
L	7	23	97.22
M	8	23	94.13
N	8	187	94.13
O	9	333	83.13

K H O R I - M A L A N   S A N D S T O N E

Trough Cross-bedding

48	10	315	69.28
49	8	296.5	79.06
50	12	247	90.81
51	12	280	93.67
52	10	301	72.10
53	8	29	90.13
54	8	45	93.13
55	10	58	91.50
56	10	33	96.73
57	8	53	97.45
58	14	311	94.55
59	16	319	82.71
60	16	288	85.50
61	14	349	94.53
62	14	356	75.59
63	12	339	81.53
64	12	311	85.18
65	20	96	94.50

Locality Number	Number of Readings (N)	θv (in degree)	L%
66	16	338	97.45
67	20	214	52.91
68	6	334	88.19
69	14	62.6	81.88
70	14	28	96.66
71	14	273.5	86.30
72	4	255	50.00
		Planar Cross-bedding	
P	6	324.6	88.38
Q	6	251	89.64
R	7	327.6	89.27
S	8	329.4	86.89
		J I R A N S A N D S T O N E	
		Trough Cross-bedding	
73	8	67.6	97.45
74	14	336	24.00
75	17	139	23.58
76	10	15	94.64
77	8	21	84.64
78	16	135	68.30
79	22	145	70.50
80	18	160.7	70.55
81	20	275	67.11
82	16	150	90.12
83	10	246	47.88
84	26	9	73.20
85	6	125	96.97

Locality Number	Number of Readings (N)	θv (in degree)	L%
86	12	50	93.67
87	12	345	95.53
88	14	335	71.99
89	14	32	96.66
90	10	165	100.00
91	110	153	96.72
92	8	150	96.59
93	14	259.5	90.71
94	12	283	70.57
95	8	48	80.86
96	8	165	50.00
97	12	75	16.67
98	12	45	45.33
99	12	180	64.39
100	12	168	74.53
		Planar Cross-bedding	
T	8	38	87.72
U	9	69	89.01

Table - 11 Sector and Formation level values of Vector Mean (θv), Vector Magnitude (L%), Standard deviation (σ) and Variance (S^2) for Khardeola, Sawa, Khori-Malan and Jiran Cross-bedded Sandstone in Bhadesar - Nimbahera area.

Sector/ Formation	Number of Readings	θv (in degree)	L%	σ	S^2
		KHARDEOLA SANDSTONE			
Sector		Trough Cross-bedding			
1	40	160	80.66	40.70	1656.41
2	28	102	66.74	52.75	2782.67
3	40	74	34.89	76.34	5828.72
		SAWA SANDSTONE			
		Trough Cross-bedding			
4	42	180	67.43	55.92	3128.04
5	36	109	20.78	92.58	8570.74
6	92	154	65.37	56.47	3189.58
7	40	358	62.81	61.47	3779.48
8	48	178	12.08	102.27	10459.67
9	24	130	64.72	52.83	2791.30
10	32	193	41.68	84.64	7165.42
11	24	109	33.40	75.14	5646.26
12	44	123	40.43	84.43	7129.67
		KHORI-MALAN SANDSTONE			
		Trough Cross-bedding			
13	53	285	72.66	45.99	2115.93
14	44	43	91.71	23.29	542.70
15	86	327	80.00	38.00	1438.00
16	68	356	15.36	93.31	8707.28
17	48	9	46.46	72.15	5206.97

Sector/ Formation Level	Number of Readings (N)	θv (in degree)	L%	σ	S^2
		J I R A N S A N D S T O N E			
		Trough Cross-bedding			
18	39	21	32.73	79.24	6280.11
19	74	123	41.65	75.73	5672.84
20	78	306	5.00	105.29	11087.76
21	72	37	36.00	77.00	5941.52
22	50	239	25.73	89.94	8090.61
23	48	148	30.00	88.35	7806.64
		K H A R D E O L A S A N D S T O N E			
Formation		Trough Cross-bedding			
	108	125	48.58	76.67	5879.44
		Planar Cross-bedding			
	36	127	83.30	29.89	893.83
		S A W A S A N D S T O N E			
		Trough Cross-bedding			
	382	147	32.00	83.41	6958.00
		Planar Cross-bedding			
	81	203	18.07	101.46	10294.80
		K H O R I - M A L A N S A N D S T O N E			
		Trough Cross-bedding			
	298	341	46.00	70.19	4927.57

Sector/ Formation Level	Number of Readings (N)	θv (in degree)	L%	σ	S^2
			Planar Cross-bedding		
	27	313	75.72	43.46	1924.15
			JIRAN SANDSTONE		
			Trough Cross-bedding		
	361	92	10.91	94.54	8938.47
			Planar Cross-bedding		
	17	58	82.04	33.42	1117.06

Table - 12 Locality, Sector and Formation level modal Vector means for the Khardeola, Sawa, Khori-Malan and Jiran Sandstone cross beds azimuths of Lower Vindhyan rocks of Bhadesar - Nimbahera area of Southeastern Rajasthan. (n in each mode is denoted by numerals within brackets)

Locality/ Sector/ Formation Level	N	Nature of distribution	Modal Vector Mean (in degree)			
			Mode I	Mode II	Mode III	Mode IV
			KHARDEOLA SANDSTONE			
Locality			Trough Cross-bedding			
1	8	Bimodal	185(6)	285(2)		
2	8	Bimodal	145(6)	75(2)		
3	12	Bimodal	165(10)	105(2)		
4	12	Unimodal	160(12)			
5	8	Bimodal	75(6)	165(2)		
6	10	Trimodal	95(6)	195(2)	345(2)	
7	10	Unimodal	110(10)			
8	12	Unimodal	110(10)			
9	8	Bimodal	315(6)	105(2)		
10	12	Bimodal	332(10)	105(2)		
11	8	Unimodal	116(8)			
			Planar Cross-bedding			
A	5	Unimodal	159(5)			
B	5	Bimodal	135(3)	195(2)		
C	8	Unimodal	98(8)			
D	6	Unimodal	125(6)			
E	6	Bimodal	105(4)	165(2)		
F	6	Bimodal	165(3)	95(3)		
			SAWA SANDSTONE			
			Trough Cross-bedding			
12	10	Quadrimodal	240(4)	165(2)	15(2)	75(2)
13	8	Unimodal	165(8)			
14	8	Unimodal	203(8)			

Locality/ Sector/ Formation Level	N	Nature of distribution	Modal Vector Mean (in degree)			
			Mode I	Mode II	Mode III	Mode IV
15	6	Bimodal	180(4)	255(2)		
16	10	Unimodal	159(10)			
17	6	Unimodal	305(6)			
18	8	Bimodal	35(6)	105(2)		
19	8	Bimodal	195(4)	120(4)		
20	8	Unimodal	150(8)			
21	6	Bimodal	345(4)	135(2)		
22	26	Bimodal	159(20)	25(6)		
23	28	Bimodal	186(20)	98(8)		
24	6	Bimodal	15(4)	105(2)		
25	12	Bimodal	153(10)	45(2)		
26	12	Bimodal	165(10)	105(2)		
27	8	Unimodal	195(8)			
28	8	Bimodal	285(4)	345(4)		
29	8	Bimodal	5(6)	285(2)		
30	8	Unimodal	345(8)			
31	8	Bimodal	150(4)	360(4)		
32	8	Unimodal	45(8)			
33	10	Unimodal	33(10)			
34	18	Quadrimodal	195(12)	45(2)	135(2)	285(2)
35	20	Trimodal	356(8)	221(7)	171(5)	
36	8	Unimodal	142(8)			
37	8	Bimodal	75(4)	150(4)		
38	8	Bimodal	60(4)	210(4)		
39	14	Bimodal	207(10)	45(4)		
40	14	Bimodal	208(10)	30(4)		
41	4	Unimodal	150(4)			
42	9	Bimodal	105(6)	45(3)		
43	9	Bimodal	30(6)	195(3)		
44	6	Unimodal	205(6)			
45	12	Unimodal	105(12)			
46	18	Bimodal	309(10)	150(8)		
47	14	Bimodal	135(12)	45(2)		

Locality/ Sector/ Formation Level	N	Nature of distribution	Modal Vector Mean (in degree)			
			Mode I	Mode II	Mode III	Mode IV
			Planar Cross-bedding			
G	10	Unimodal	153(10)			
H	10	Unimodal	207(10)			
I	11	Unimodal	215(11)			
J	10	Unimodal	213(10)			
K	8	Unimodal	26(8)			
L	7	Unimodal	23(7)			
M	8	Unimodal	23(8)			
N	8	Unimodal	187(8)			
O	9	Unimodal	333(9)			
			KHORI-MALAN SANDSTONE			
			Trough Cross-bedding			
48	10	Trimodal	345(6)	225(2)	285(2)	
49	8	Bimodal	315(6)	225(2)		
50	12	Unimodal	247(12)			
51	12	Unimodal	280(12)			
52	10	Trimodal	315(6)	45(2)	255(2)	
53	8	Bimodal	15(6)	75(2)		
54	8	Unimodal	45(8)			
55	10	Unimodal	58(10)			
56	10	Unimodal	53(10)			
57	8	Unimodal	53(8)			
58	14	Unimodal	311(14)			
59	16	Unimodal	319(16)			
60	16	Unimodal	288(16)			
61	14	Unimodal	349(14)			
62	14	Trimodal	15(10)	285(2)	315(2)	
63	12	Unimodal	339(12)			
64	12	Unimodal	311(12)			

Locality/ Sector/ Formation Level	N	Nature of distribution	Modal Vector Mean (in degree)			
			Mode I	Mode II	Mode III	Mode IV
65	20	Unimodal	96(20)			
66	16	Unimodal	338(16)			
67	20	Bimodal	191(14)	325(6)		
68	6	Bimodal	315(4)	15(2)		
69	14	Bimodal	85(9)	21(5)		
70	14	Unimodal	28(14)			
71	10	Unimodal	273.5(10)			
72	4	Bimodal	195(2)	315(2)		
			Planar Cross-bedding			
P	6	Unimodal	325(6)			
Q	6	Bimodal	261(5)	195(1)		
R	7	Unimodal	328(7)			
S	8	Bimodal	315(6)	5(3)		
			JIRAN SANDSTONE			
			Trough Cross-bedding			
73	8	Unimodal	68(8)			
74	14	Unimodal	336(14)			
75	17	Trimodal	148(9)	30(4)	285(4)	
76	10	Unimodal	15(10)			
77	8	Bimodal	5(6)	75(2)		
78	16	Bimodal	143(14)	15(2)		
79	22	Quadrimodal	135(14)	195(4)	75(2)	285(2)
80	18	Bimodal	154(16)	285(2)		
81	20	Bimodal	289(16)	165(4)		
82	16	Unimodal	150(16)			
83	10	Bimodal	205(6)	330(4)		
84	26	Unimodal	9(26)			
85	6	Unimodal	125(6)			
86	12	Unimodal	50(12)			

Locality/ Sector/ Formation Level	N	Nature of distribution	Modal Vector Mean (in degree) Mode I	Mode II	Mode III	Mode IV
87	12	Unimodal	345(12)			
88	14	Bimodal	324(12)	75(2)		
89	14	Unimodal	32(14)			
90	10	Unimodal	165(10)			
91	10	Unimodal	153(10)			
92	8	Unimodal	150(8)			
93	14	Unimodal	260(14)			
94	12	Bimdoal	273(10)	45(2)		
95	8	Bimodal	65(6)	345(2)		
96	8	Bimodal	175(6)	15(2)		
97	12	Trimodal	125(6)	300(4)	15(2)	
98	12	Bimodal	105(6)	345(6)		
99	12	Bimodal	183(10)	15(2)		
100	12	Bimodal	195(8)	105(4)		
			Planar Cross-bedding			
T	8	Unimodal	38(8)			
U	9	Unimodal	69(9)			
			KHARDEOLA SANDSTONE			
Sector			Trough Cross-bedding			
1	40	Bimodal	163(38)	285(2)		
2	28	Trimodal	88(19)	169(7)	345(2)	
3	40	Bimodal	111(24)	326(16)		
			SAWA SANDSTONE			
			Trough Cross-bedding			
4	42	Trimodal	184(38)	15(2)	75(2)	
5	36	Trimodal	146(2)	326(11)	39(5)	
6	92	Bimodal	163(79)	28(13)		
7	40	Quadrimodal	350(19)	37(11)	285(6)	150(4)

Locality/ Sector/ Formation Level	N	Nature of distribution	Modal Vector Mean (in degree)			
			Mode I	Mode II	Mode III	Mode IV
8	48	Trimodal	193(26)	24(20)	285(2)	
9	24	Bimodal	160(16)	68(8)		
10	32	Bimodal	198(24)	38(8)		
11	24	Trimodal	35(9)	201(9)	105(6)	
12	44	Trimodal	135(29)	309(10)	51(5)	
		KHORI-MALAN SANDSTONE				
		Trough Cross-bedding				
13	52	Bimodal	283(50)	45(2)		
14	44	Unimodal	43(44)			
15	86	Unimodal	327(86)			
16	68	Trimodal	327(34)	96(20)	191(14)	
17	48	Bimodal	41(30)	282(18)		
		JIRAN SANDSTONE				
		Trough Cross-bedding				
18	39	Trimodal	330(20)	63(10)	148(9)	
19	74	Quadrimodal	126(39)	10(17)	186(14)	285(40
20	78	Trimodal	150(36)	293(22)	6(20)	
21	72	Bimodal	13(52)	159(20)		
22	50	Trimodal	263(25)	158(13)	41(12)	
23	48	Quadrimodal	118(18)	191(16)	11(7)	311(7)
		KHARDEOLA SANDSTONE				
Formation		Trough Cross-bedding				
	108	Trimodal	101(48)	165(40)	324(20)	
		Planar Cross-bedding				
	36	Bimodal	107(21)	161(15)		

Locality/ Sector/ Formation Level	N	Nature of distribution	Modal Vector Mean (in degree) Mode I	Mode II	Mode III	Mode IV
			S A W A S A N D S T O N E			
			Trough Cross-bedding			
	382	Trimodal	165(252)	21(109)	286(21)	
			Planar Cross-bedding			
	81	Bimodal	196(49)	12(32)		
			K H O R I - M A L A N S A N D S T O N E			
			Trough Cross-bedding			
	298	Bimodal	346(276)	201(22)		
			Planar Cross-bedding			
	27	Unimodal	313(27)			
			J I R A N S A N D S T O N E			
			Trough Cross-bedding			
	361	Trimodal	23(151)	158(148)	284(62)	
			Planar Cross-bedding			
	17	Unimodal	58(17)			

locality, sector and formation level. For Polymodal distributions, Vector mean for each subpopulation clustering around a mode was calculated separately at locality and sector level for each formations (Kelling, 1969; P. 863) and is here designated 'Modal Vector mean' (Table - 12). This was considered necessary in view of the possible involvement of two or more independent depositing current systems, as first point out by Tanner (1959) for correctly analysing polymodal distribution.

In view of the known genetic relationship between the primary directional features and the prevailing current system (Potter and Pettijohn, 977) the results so obtained, indeed can be approximately interpreted for reconstructing paleoflow system through space and time.

KHARDEOLA SANDSTONE

The Khardeola Formation is composed of mainly sandstone and shale. The sandstone is yellowish pink, pinkish white and blackish grey in colour and characterised by very fine to coarse grained, massive and cross bedded. As described earlier, the sandstone is immature to mature, with massive unit forming mostly basal part where as cross bedded sandstone forming upper part of the formation.

Paleocurrent and sediment dispersal patterns of the Khardeola Sandstone were studied mainly on the basis of orientation of cross beds. Frequency distribution of cross bedding azimuths for trough and planar cross beds at locality, sector and formation level are shown as rose diagrams (Fig. 24

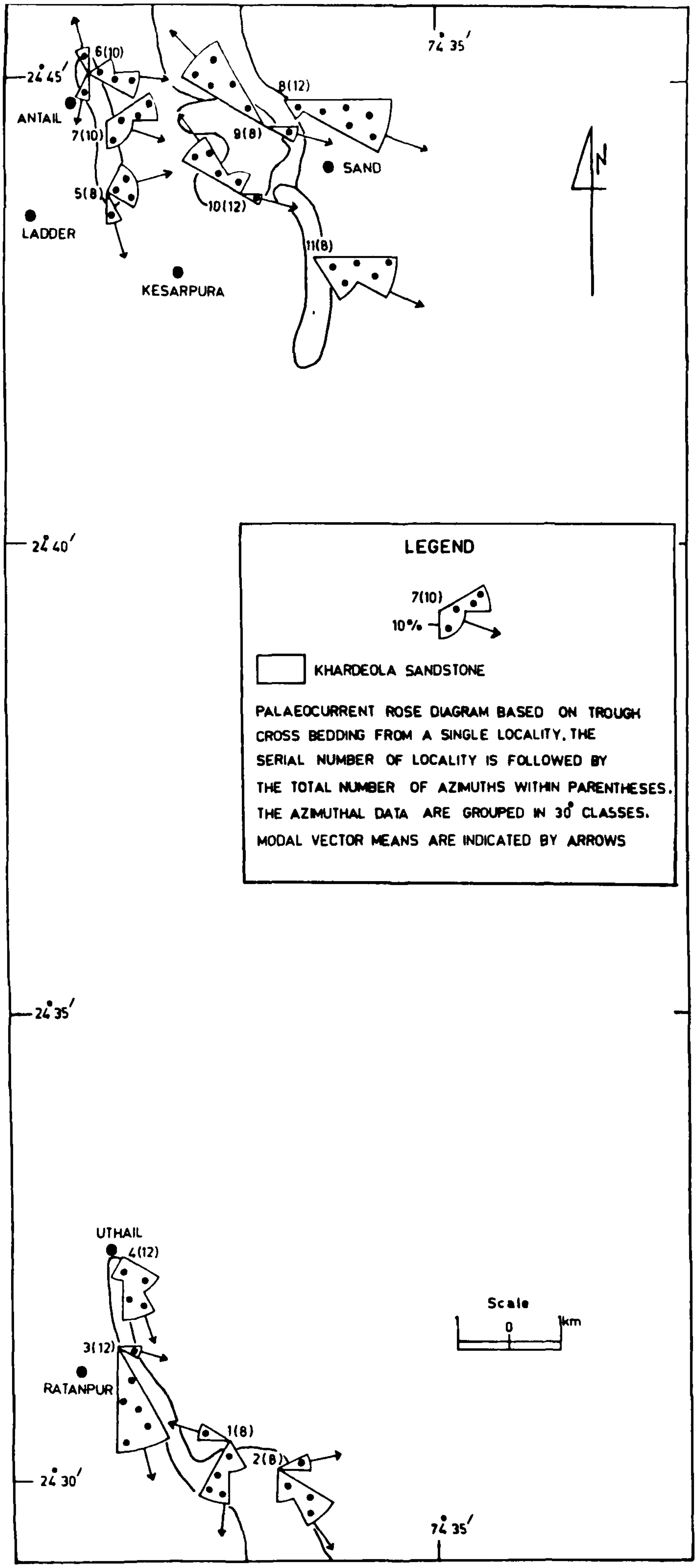

Fig 24 Locality-level Palaeocurrent map for Trough cross beds of Khardeola

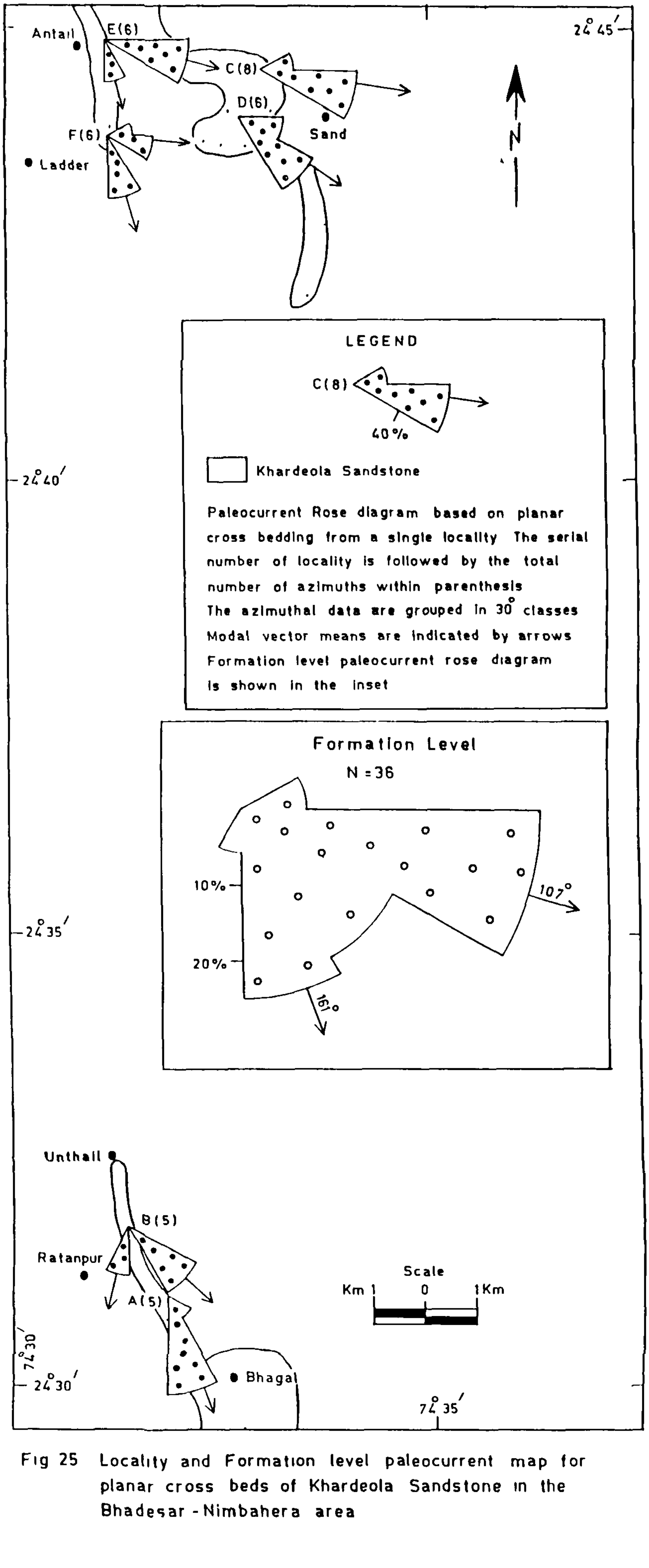

Fig 25 Locality and Formation level paleocurrent map for planar cross beds of Khardeola Sandstone in the Bhadesar - Nimbahera area

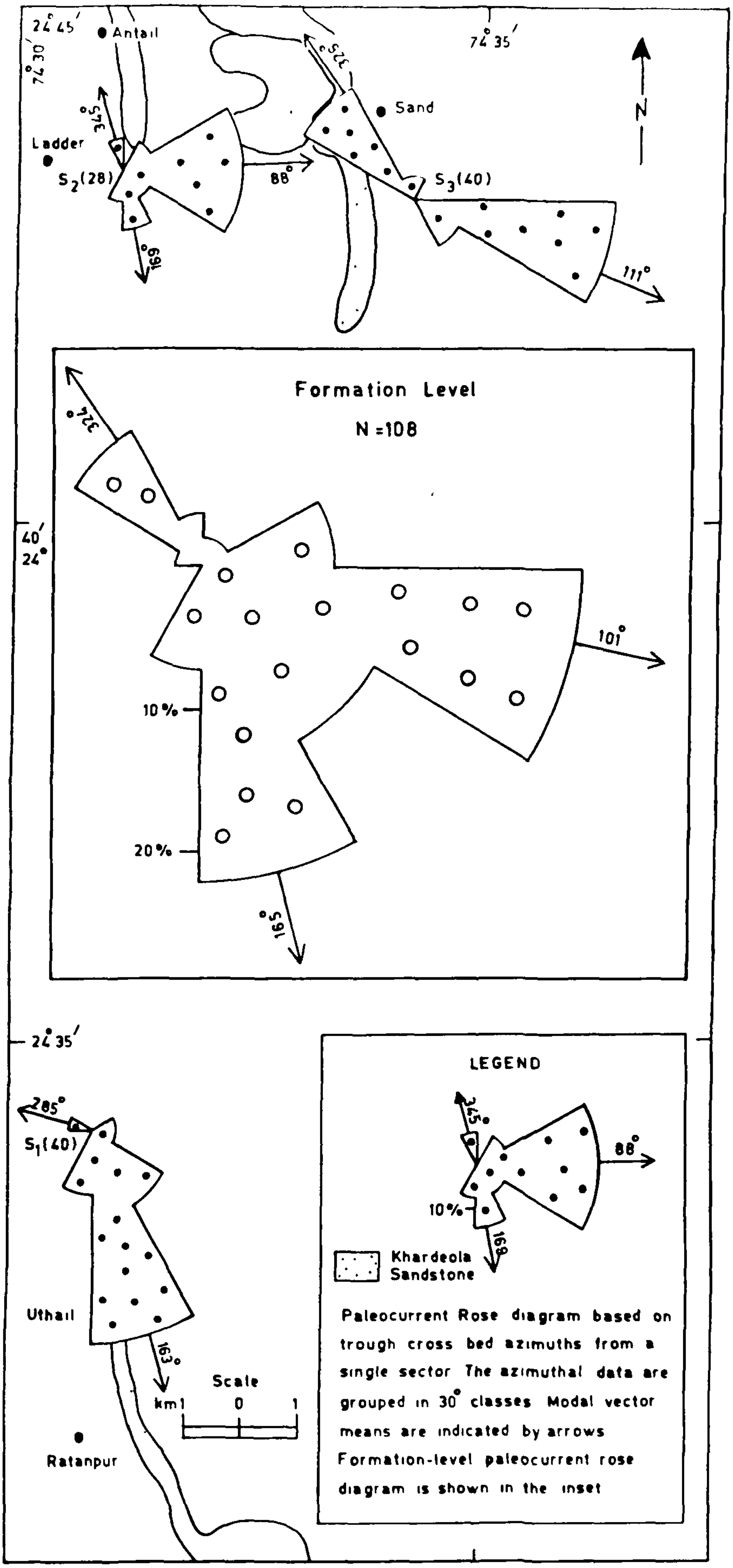

Fig.26 Sector and Formation level paleocurrent map for trough cross beds of Khardeola Sandstone in the Bhadesar-Nimbahera area

to 26). There are some differences in the frequency distribution of trough and planar cross beds. At 7 localities out of 11 examined, the frequency distribution is bimodal and trimodal for trough cross beds (Table - 12 and Fig. 24). Trough cross beds at locality level display polymodal distribution commonly with primary modes directed toward easterly (90-120^{o}), East north east (60-90^{o}), South east south (150-180^{o}), South east (120 - 150^{o}), South west south (180-210^{o}), North west (300-330^{o}) and secondary modes towards South west south (180-210^{o}), easterly (90-120^{o}), South east south (150-180^{o}), North west (300-330^{o}) and Westerly (270-300^{o}). Similarly planar cross-bedding yield unimodal to bimodal distribution with modal class directed toward easterly (90-120^{o}), South east south (150-180^{o}), South (180-210^{o}) and South east (120-150^{o}) (Fig. 25).

The bimodal to trimodal distribution of trough and planar cross bedding occurs more commonly at locality 1, 2, 3, 5, 6, 9, 10, B, E and F display 90^{o} or nearly 180^{o} reversal of paleocurrents, generally from north west to southeast (Fig. 24 & 25). The vector mean (θv) for planar and trough cross beds at various locality shows a wide range of distribution ranges from 95^{o} to 343^{o}. But 13 out of 17 locality, the vector mean values lie between 95 to 159, that is, within 64^{o} of arc (Table - 10 and Fig. 24 & 25). The foreset azimuthal data from all locality lumped to yield data at sector and formation level for planar and trough cross bedding were plotted graphically (Fig. 25 & 26). The corresponding statistics including vector mean, variance, standard deviation as listed in Table - 11. The foreset azimuth at sector level display mostly bimodal to trimodal distribution for trough cross beds with principal modes oriented towards east (90-120^{o}), south east south (150-180^{o}) and secondary modes towards south east south (150-180^{o}), west (270-300^{o}), north westerly (300-330^{o}) (Fig. 26 & Table 12). By contrast at formation level the foreset azimuth shows trimodal distribution for trough cross bedding with principal and secondary modes oriented towards easterly (90-120^{o}) and south east south (150-180^{o}), northerly (330-360^{o}) respectively (Fig. 26). Similarly planar cross beds at formation level show bimodal distribution with principal and secondary modes oriented toward east (90-120^{o}) and south east south (150-180^{o}) respectively (Fig. 25).

The vector magnitude (L) show consistency at the locality level. However, the consistency decreases at sector and formation level. The corresponding variability (variance) around vector mean direction for trough cross beds ranges from 1656 to 5828. However, the total variance for trough and planar cross beds are 5879 and 894 respectively (Table - 11).

The polymodal patterns of trough cross beds, lower values of vector magnitude (49%) and higher variance (5879) indicates large azimuthal dispersion perhaps due to diverse current systems of coastal environments (Klein, 1967b, Selley, 1968) including tidal and longshore currents. The diagonally/ oppositely oriented modal classes of trough cross beds at various locality of Khardeola Sandstone are genetically significant and may correspond to ebbtidal/foreshore directed toward east or southeast and Backshore/flood tidal currents parallel to or across the shore line toward west or Northwest. These are most probably represent tidally influenced Nearshore environments (Klein, 1971; Ginsberg, 1975; De Boer et al, 1988).

SAWA SANDSTONE

The succeeding Sawa Formation, characterised by medium to coarse grained, immature, cross bedded, sandstone. As stated earlier, the sandstone is shaley and pebbly in the lower and middle part respectively where as massive to cross bedded in upper part.

Frequency distribution of cross bedding azimuths are highly scattered in the Sawa Sandstone both at the locality and sector level. There are some differences in the frequency distribution of trough and planar beds. At locality level, trough cross foreset azimuths are unimodal to quadrimodal (Fig. 27 & Table 12). At 23 localities out of 36 examined, the frequency distribution is polymodal with principal and secondary modes show multi direction. Similarly planar cross beds display mostly unimodal distribution with principal modes directed towards easterly (Fig. 28). Histograms at the sector level are bimodal to trimodal except in sector S_7 where it is quadrimodal (Fig. 29). It is noteworthy that at both levels of sampling the principal modes point, by and large, towards a easterly and south easterly direction while the secondary modes are directed either at right angles or in the reverse direction. At formation level the foreset azimuths display trimodal distribution with primary modes oriented toward south

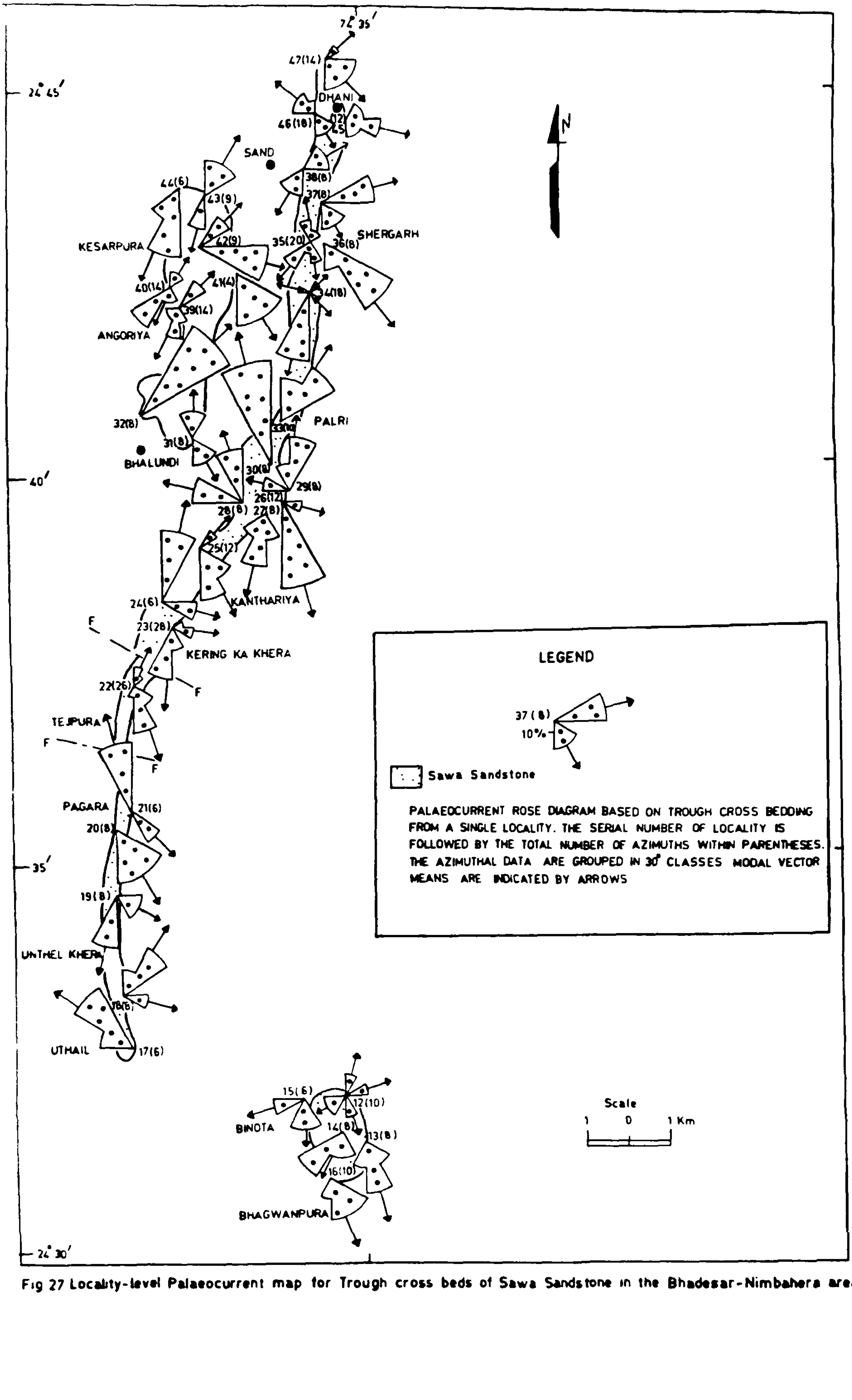

Fig 27 Locality-level Palaeocurrent map for Trough cross beds of Sawa Sandstone in the Bhadesar-Nimbahera area

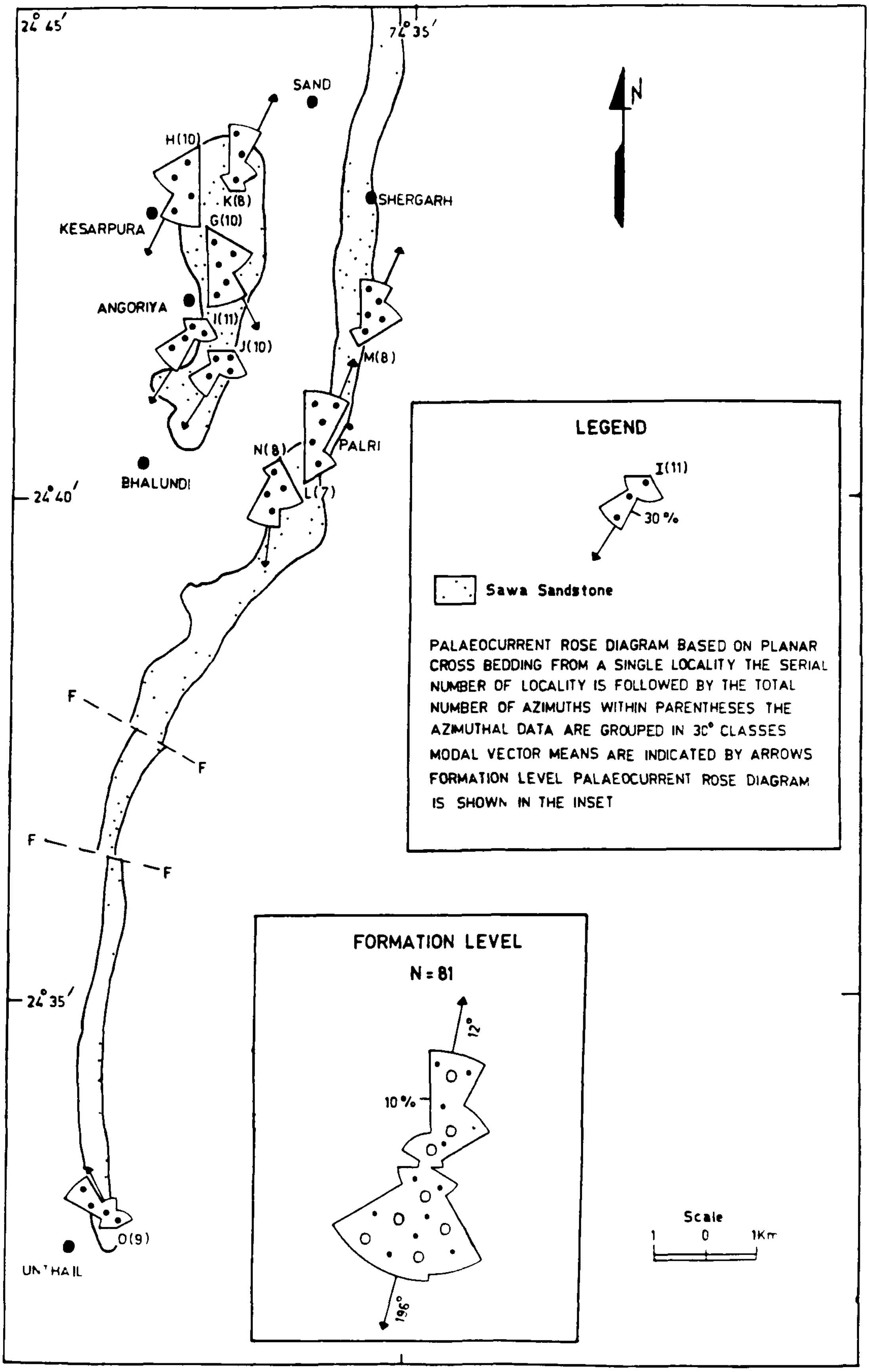

Fig 28 Locality and Formation-level Palaeocurrent map for Planar cross beds of Sawa Sandstone in the Bhadesar-Nimbahera area

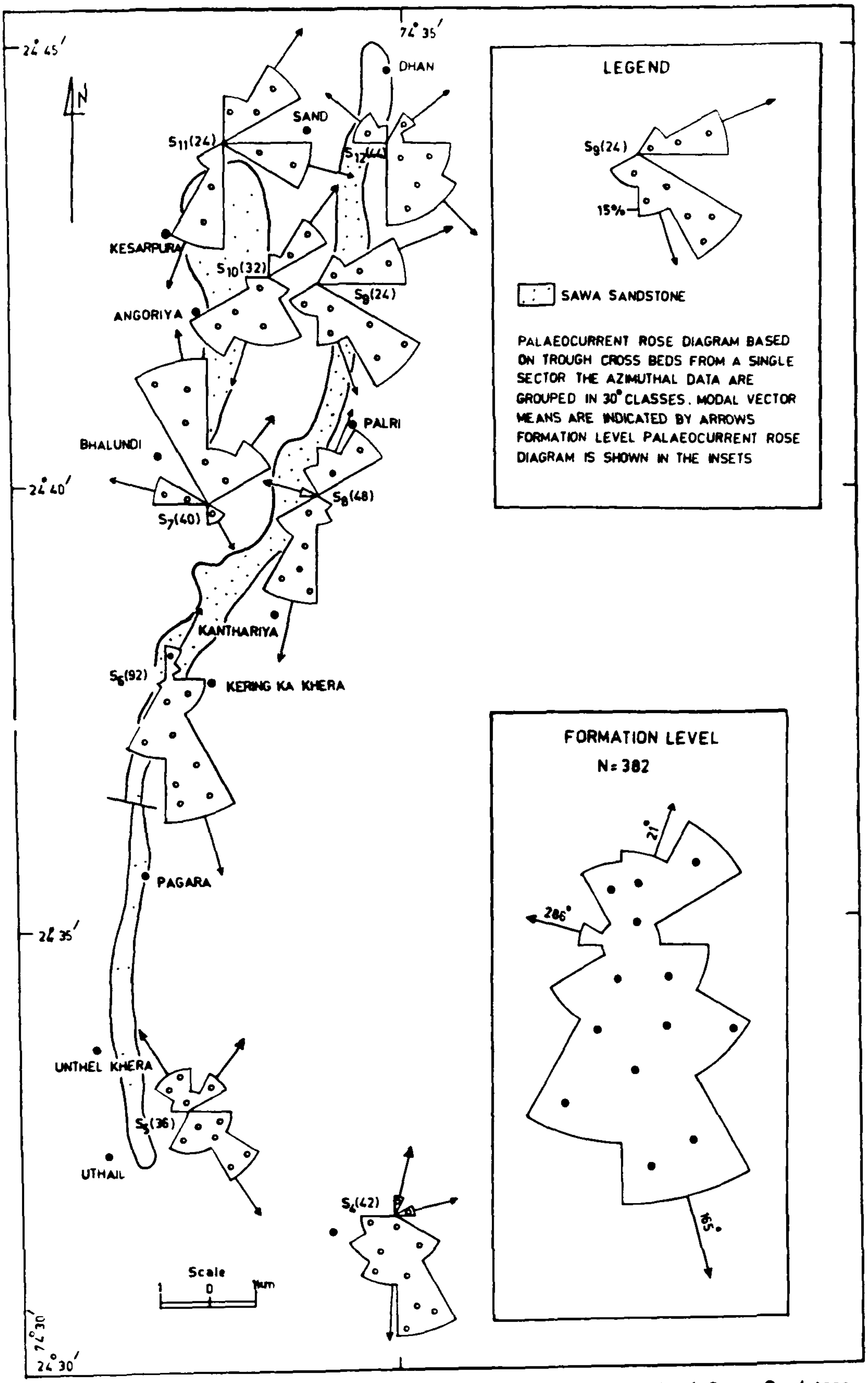

Fig 29 Sector and Formation level Palaeocurrent map for Trough cross beds of Sawa Sandstone in the Bhadesar-Nimbahera area.

east while secondary modes toward north and westerly directions (Fig. 29 & Table 12). This large scatter of cross bed azimuth is also reflected by the vector magnitude values which are a measure of the concentration of the vector azimuths. At the locality level, the values ranges from 15 to 100% indicating a very wide range of scatter from locality to locality but 34 of the 45, the values are larger than 74% (Table 10). At the sector level the values are smaller on an average 41% and range between 21 and 67.43% (Table 11).

The vector mean azimuth (θv) for planar and trough cross beds at various locality shows a wide span of distribution ranges from 6 to 347^{o} but 25 out of 45 locality, the vector mean values lie between 141 to 225^{o}, that is within 84^{o} of arc as recorded in Table - 10 and is evident from paleocurrent maps in Figure 27 & 28. However, sector to sector variation of vector mean azimuth is small except one sector (S_7), all values lie within 84^{o} of arc between 109^{o} and 193^{o} (Table - 11). This means that the locality to locality variation of vector mean azimuth is large but at sector level, this varition becomes prominent. The grand vector mean azimuth at the formation level for trough and planar cross bed are 147^{o} and 203^{o} respectively. The variance (S^2) of foreset azimuths at the sector level varies from 2791 to 10460. However, the total variance for trough and planar cross beds are 6958 and 10295 respectively (Fig. 28 & 29 and Table - 11).

The bimodal to trimodal paleocurrent patterns of cross beds in Sawa Sandstone, lower values of vector magnitude and higher value of standard deviation and variance may imply large dispersion in selective areas (particularly Binota and Palri) perhaps due to intermixing of nearshore coastal environments including rip, longshore and tidal currents (Hunter et al, 1979; Davis, 1985; Einsele, 1992).

KHORI-MALAN SANDSTONE

The Khori-Malan Sandstone is fine grained, cross bedded and dark green to purple, in places dark brown in colour. Paleocurrent and sediment dispersal patterns of the Khori-Malan Sandstone were studied mainly on the basis of orientation of cross beds.

Frequency distribution of cross bed azimuths for trough and planar cross beds at locality, sector and formation level are shown as rose diagrams (Fig. 30, 31 & 32). Frequency distribution of trough and planar beds have some difference. Trough cross beds at locality level display unimodal to trimodal distribution. At 16 localities out of 25 examined, the frequency distribution remains unimodal with principal modes directed mostly towards north west and easterly (Fig. 30 and Table 12). Similarly planar cross beds display unimodal to bimodal distribution with principal mode directed toward north west (300-330°), west north west (240-270°) and secondary modes toward north east north (0-30°) and south (180-210°) (Fig. 31). The bimodal to trimodal distribution of trough cross beds occurs more commonly at locality 48, 49, 52, 53, 62, 67, 68, 69, Q and S (Fig. 30 & 31 and Table 12). Frequency distribution at sector level are unimodal to trimodal with principal modes oriented towards north westerly (300-330°) and

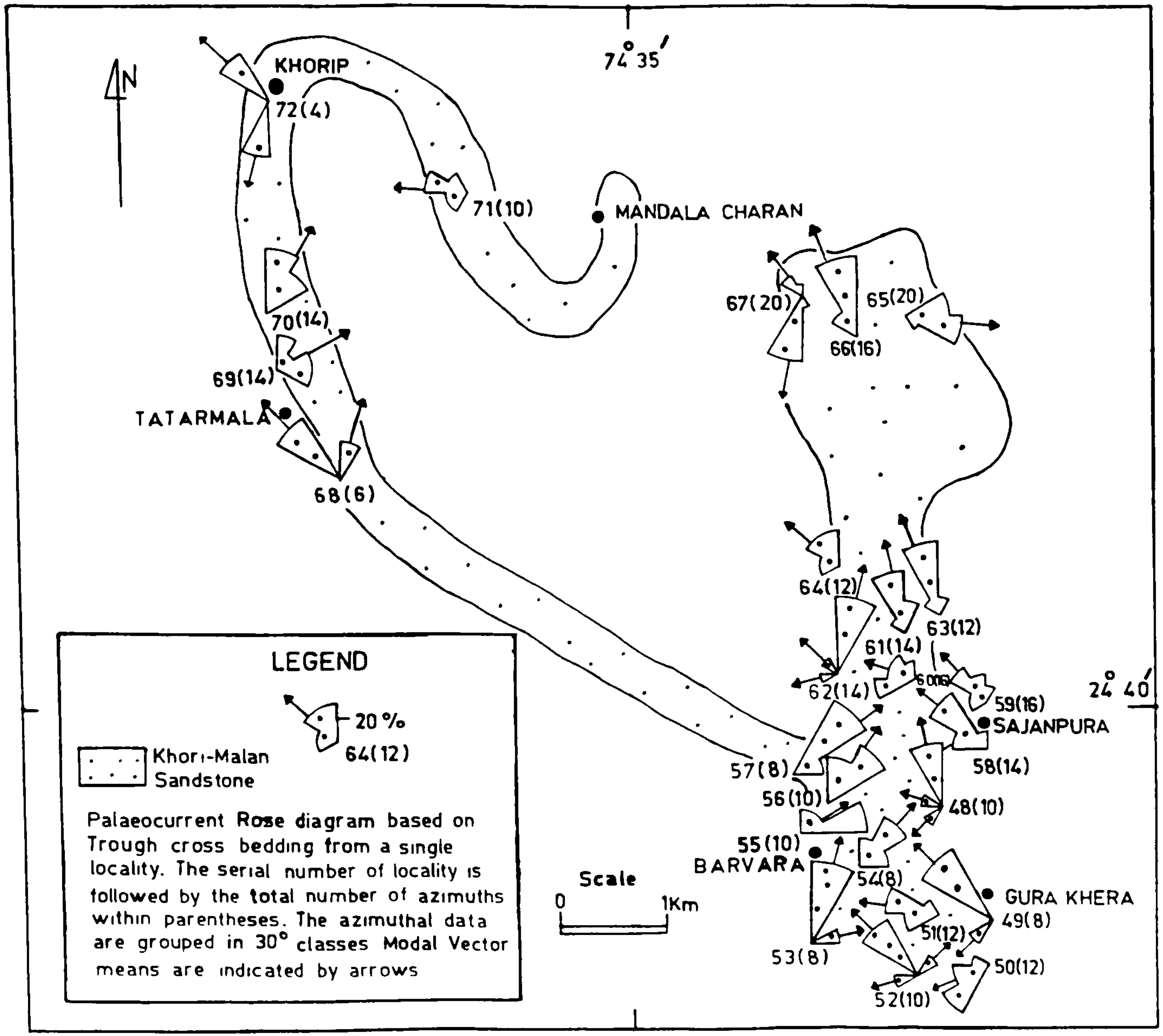

Fig.30 Locality-level Palaeocurrent map for Trough cross beds of Khori-Malan Sandstone in the Bhadesar-Nimbahera area.

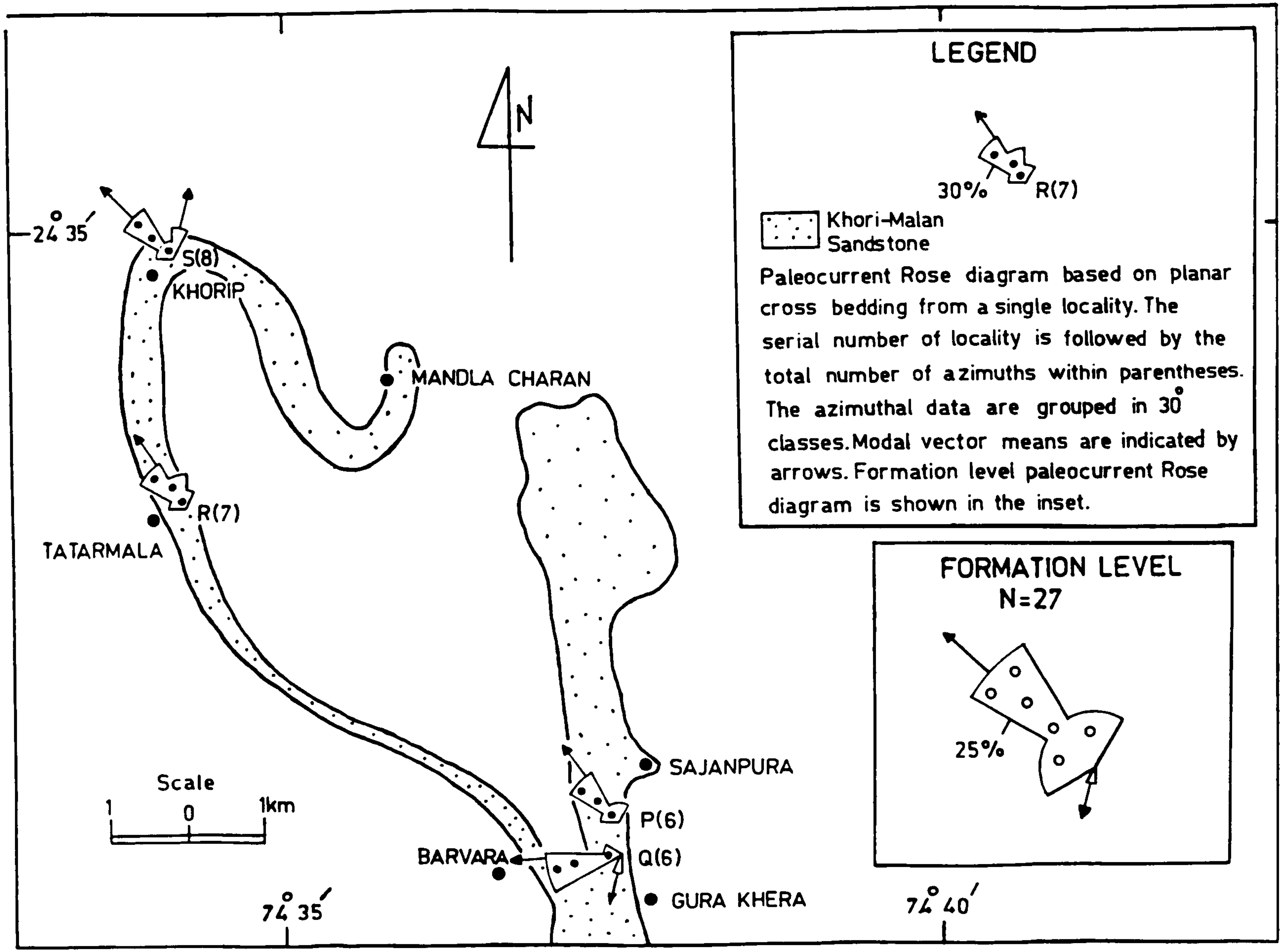

Fig.31 Locality and Formation level Paleocurrent map for planar cross beds of Khori-Malan Sandstone in the Bhadesar-Nimbahera area.

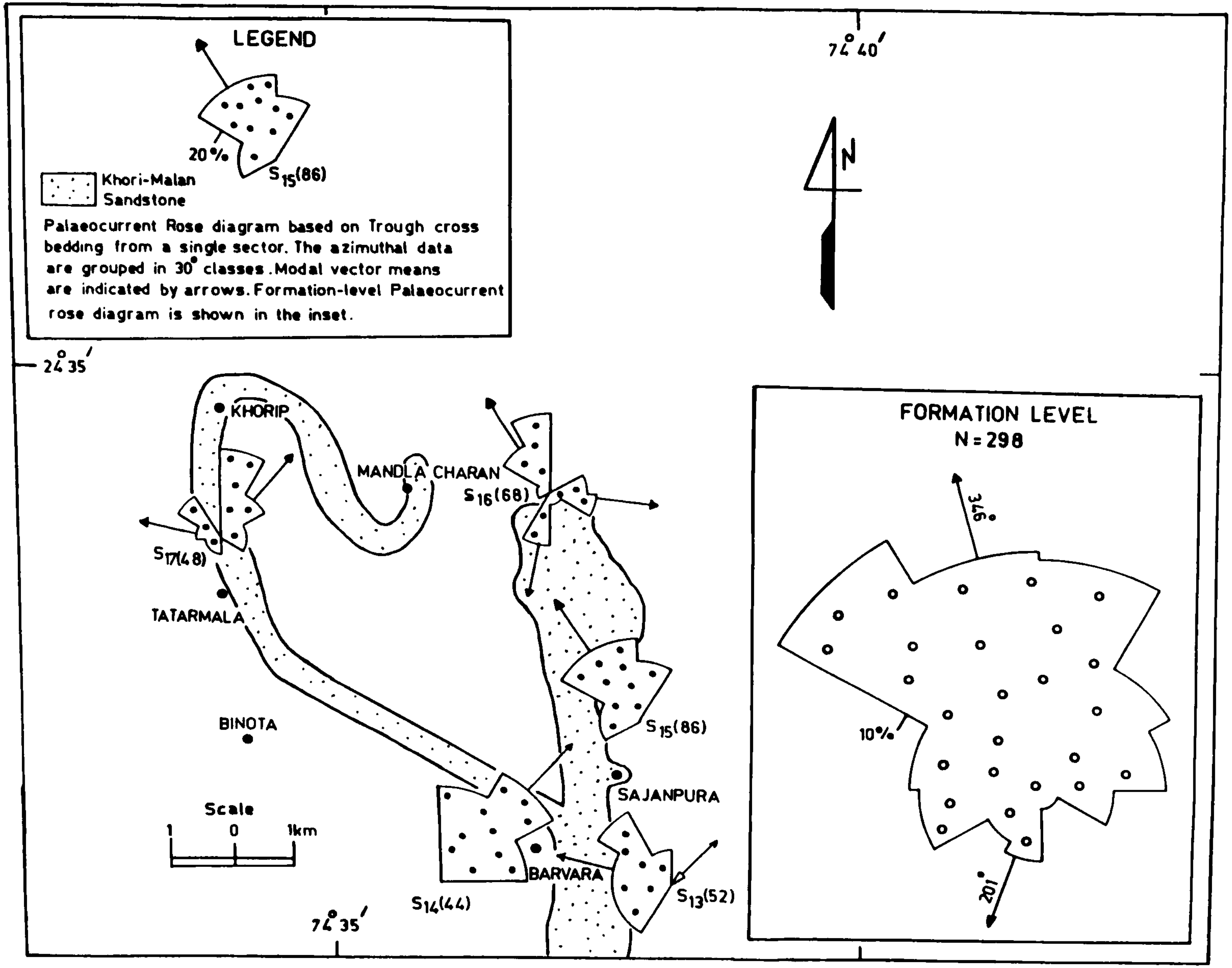

Fig.32 Sector and Formation-level Palaeocurrent map for trough cross beds of Khori-Malan Sandstone in the Bhadesar-Nimbahera area.

north easterly (30-60°) while the secondary modes are directed either right angle or in the reverse direction (Fig. 32 and Table 12). At formation level, the foreset azimuth display nearly unimodal distribution for both trough and planar cross beds with modal class oriented toward north west (300-330°). The large scatter of cross bed azimuth is also reflected by the vector magnitude values. At the locality level, the values ranges from 50 to 97.45% indicating a scatter from locality to locality (Table 10). At the sector level the values are smaller on an average 61% and range between 15.36 to 91.71% (Table 11).

The vector mean azimuth (θv) for planar and trough cross beds at various locality level shows a wide span of distribution ranging from 214 to 96°. But 16 out of 25 locality, the vector mean values lie between 280 to 356°, that is within 76° of arc as recorded in Table-10 and is evident from paleocurrent maps in Figure 30 & 31. However, at the sector level variation of vector mean azimuth is small, except one sector all values lie within 84° of arc between 285 to 9°. This mean that the locality to locality variation of vector mean azimuth is large but at sector level, this variation becomes prominent. The grand vector mean at the formation level for trough and planar cross beds are 341° and 313° respectively. The variance (S^2) of foreset azimuths at the sector level varies from 543 to 8707. However the total variance for trough and planar cross beds are 4928 and 1924 respectively (Table-11).

The unimodal pattern and high vector magnitude values for large majority of the locality level distribution suggest very low variability of currents within individual localities. This is in agreement with the behaviour of longshore and tidal currents believed responsible for the origin of the Khori-Malan Sandstone cross bedding. Longshore currents behave as unidirectional fluvial currents during high energy period and bring about rapid migration of dunes (Davis and Fox, 1972, P.407). The predominant north west or west dipping directions of cross strata reflect a dominance of landward driven currents.

Tidal currents transport sediment only during one phase of the tidal cycle either onshore or off shore depending upon the dominance of flood or ebb tidal currents (Klein, 1970a, 1985; Kranck, 1972, P. 599). For this reason Recent intertidal sediments show abundance of unimodal orientation of cross strata, low variance and scarcity of herringbone pattern (Klein, 1970, P. 1118; 1985). Thus in the study area dominance of unimodal patterns of cross beds azimuths and their low variability at individual localities in all probability may reflect that the Khori-Malan Sandstone may be deposited by landwards (north west or west), unidirectional longshore currents or by flood dominating tidal currents and also of offshore and onshore currents during transgression of sea.

JIRAN SANDSTONE

The succeeding Jiran Formation characterised by fine to very fine grained, profusely trough cross bedded and pinkish brown to greyish white sandstone.

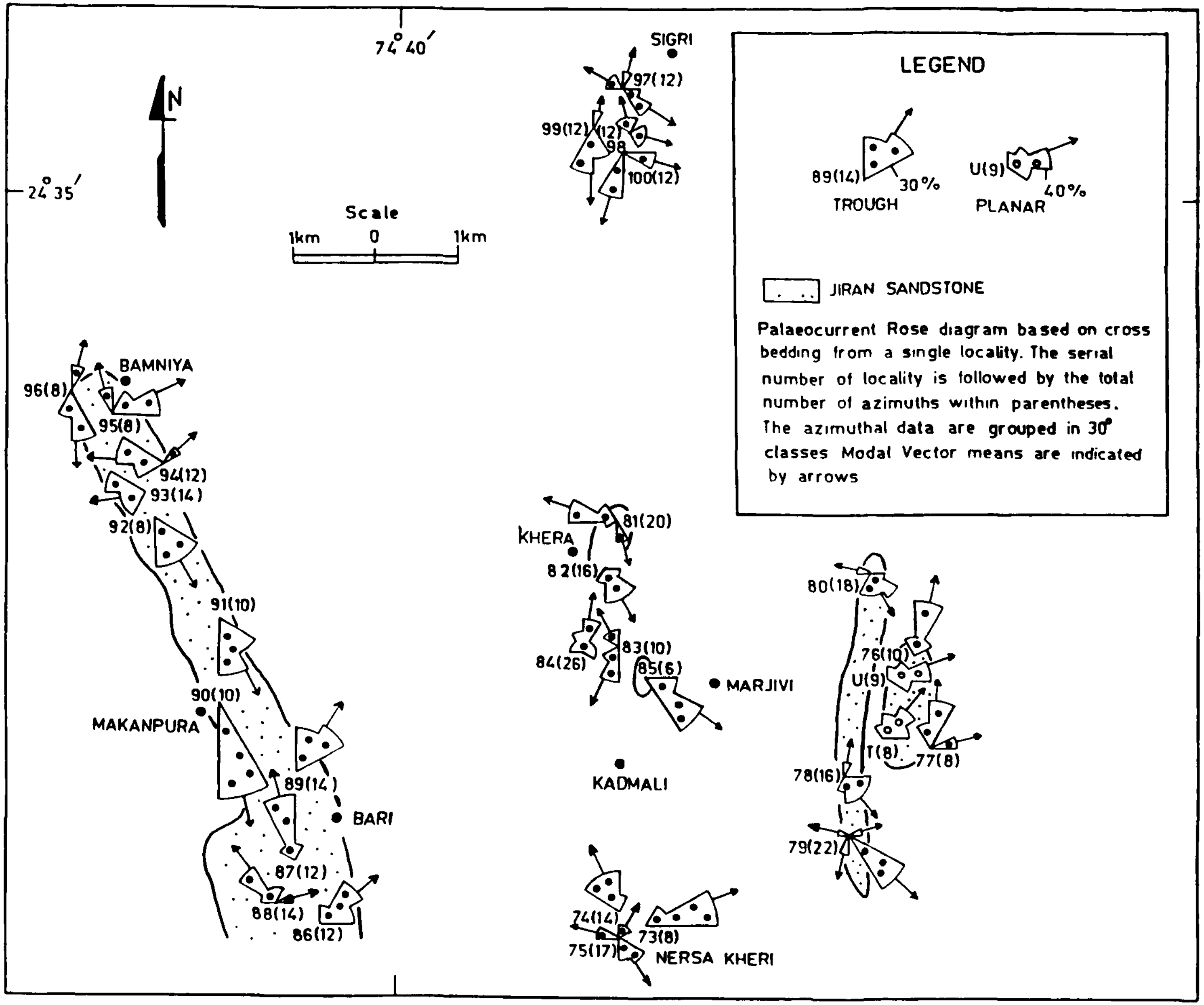

Fig.33 Locality-level Palaeocurrent map for cross beds of Jiran Sandstone in the Bhadesar-Nimbahera area.

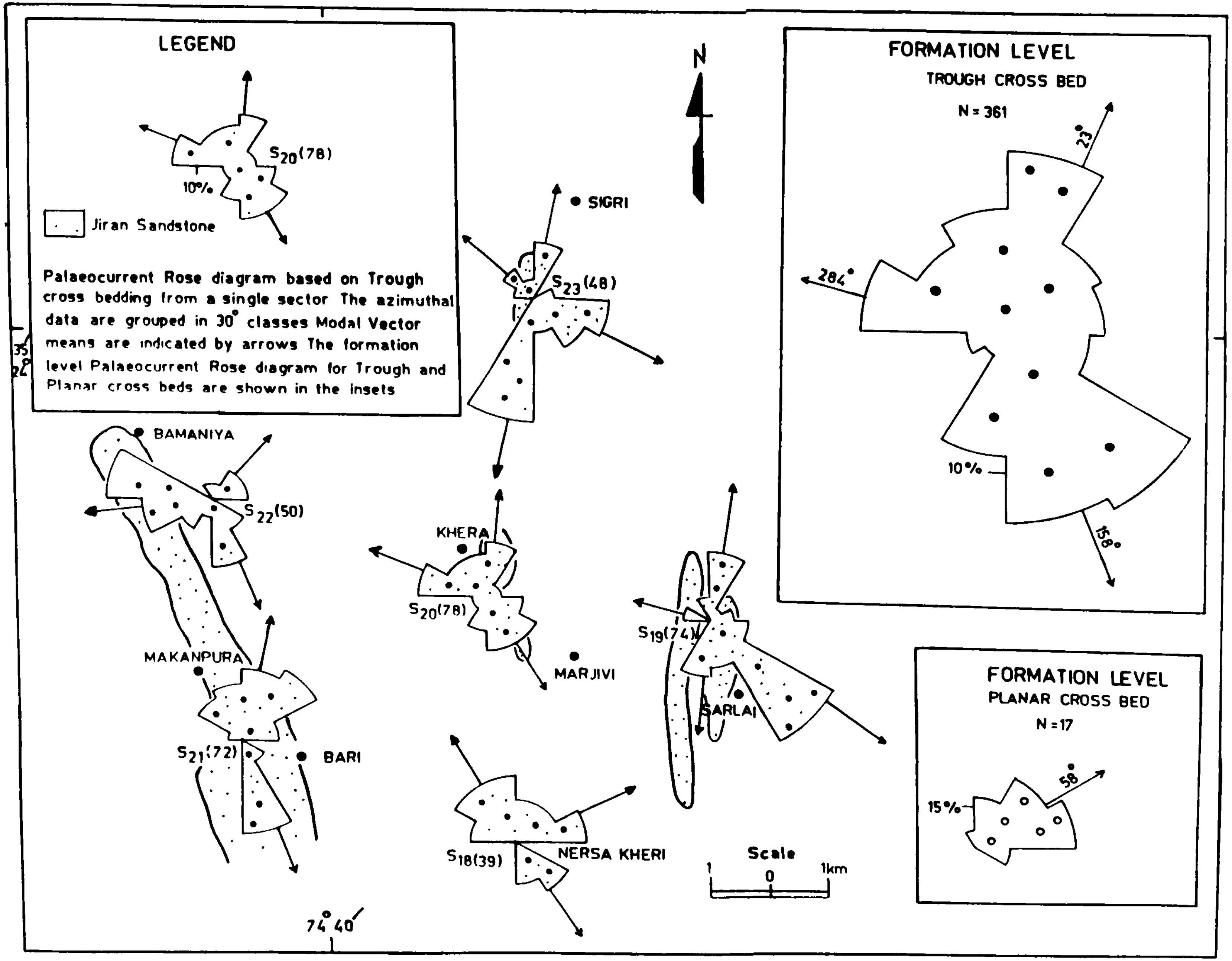

Fig.34 Sector and Formation level Palaeocurrent map for cross beds of Jiran Sandstone in the Bhadesar-Nimbahera area.

Frequency distribution of cross bedding azimuths in Jiran Sandstone for trough cross beds are highly scattered at locality (Fig. 33) and sector level (Fig. 34). The locality level distribution of trough cross bedding azimuths are commonly unimodal and bimodal and are infrequently trimodal and quadrimodal. Many bimodal distributions are bipolar with two modes oriented at 180^{o} and in others, the two modes are oriented at approximately 90^{o} toward north west and south east. In trimodal and quadrimodal distributions especially in trough cross bedded units, the various modes are oriented at nearly 90^{o} (Fig. 33 and Table-12). The polymodal distribution of trough cross bedding occurs more commonly at locality 75, 77 to 81, 83, 88, 89 and 94 to 100 (Fig. 33). However, planar cross beds (locality T & U) show unimodal distribution with modal class oriented toward north east. Histograms at sector level are polymodal with principal and secondary modes oriented towards north east, south east, north west or west (Fig. 34 and Table-12). At formation level the foreset azimuth display trimodal distribution for trough cross beds with primary modes oriented towards north east while secondary modes towards south east and westerly but unimodal distribution in the case of planar cross beds with modal class oriented toward east (Fig. 34 and Table-12).

The large scatter of cross beds azimuth is also reflected by vector magnitude. At locality the values ranges from 17 to 100% indicating a very wide of scatter but 18 localities out of 30 the values is more than 68% (Table-10). However, the vector magnitude values decreases (5-42%) and 11%

for sector and formation level respectively, signifying that great consistency of depositional system in small area of locality than in large size of sector and formation level.

The vector mean azimuth (θv) for planar and trough cross beds at various locality shows a wide range of distribution from 9 to 345^{o}, but 10 out of 30 locality, the vector mean values lie in between 68^{o} to 153^{o} that is within 85^{o} (Table-10 and Fig. 33). However, at sector level variation in vector mean is also wide due to polymodal distribution of foreset azimuths, while grand vector mean at formation level for trough and planar cross beds are 92^{o} and 58^{o} respectively (Fig. 34 and Table-11).

The polymodal paleocurrent patterns of cross beds, lower values of vector mean (11%) and higher value of standard deviation (94.54) and variance (8938.47) may imply large azimuthal dispersion and therefore suggest multidirectional currents characteristic of the coastal environment (Hunter et al, 1979; Davis, 1985; Reinson, 1984; Einsele, 1992) including tidal flats, tidal channels, lagoons, beaches and inlets where sediments was transported down slope, upslope and accross slope as documented by Klein (1967b,P. 373). But the Paleoflow patterns so deduced suggests a dominant role of south easterly directed depositional currents and oppositely oriented westerly or diagonally directed north easterly paleoflow currents. The south easterly paleocurrent system apparently was represent seaward dipping cross beds of foreshore beach whereas westward directed currents was of landward dipping cross bed of Backshore beach sediments. However diagonally oriented subsidary cross beds toward north east may correspond to longshore currents parallel to the inferred shoreline in the study area during the deposition of Jiran Sandstone.

CONSISTENCY OF PALEOFLOW AND PALEOSLOPE THROUGH TIME

For a paleocurrent analysis of directional data in order to determine the consistency of paleocurrent pattern or lack of it from base to top of the Lower Vindhyan rocks, the foreset azimuthal data for trough and planar cross bedding were analysed separately for each formation, both graphically and statistically. The rose diagrams and corresponding statistics in figure 35 bring out pictorially the variation in paleocurrent pattern in the lower Vindhyan rocks of study area from Khardeola Formation at the base to Jiran Formation at the top.

Evidently the trimodal paleoflow pattern as deduced from trough cross bedding in three formation namely Khardeola, Sawa and Jiran. As the principal mode directed toward easterly (90-120^{o}), south southeasterly (150-180^{o}) and south east (120-150^{o}) with corresponding grand mean toward 125^{o}, 147^{o} and 92^{o} respectively, for Khardeola, Sawa and Jiran Sandstone Formation (Fig. 35). The Khori-Malan Sandstone Formation show nearly unimodal paleoflow pattern for trough cross bed with principal mode directed reversely to previous mention direction of three formation i.e. towards northeast (300-330^{o}) with grand mean toward 341^{o} (Fig. 35).

Similarly for planar cross bedding as recorded in

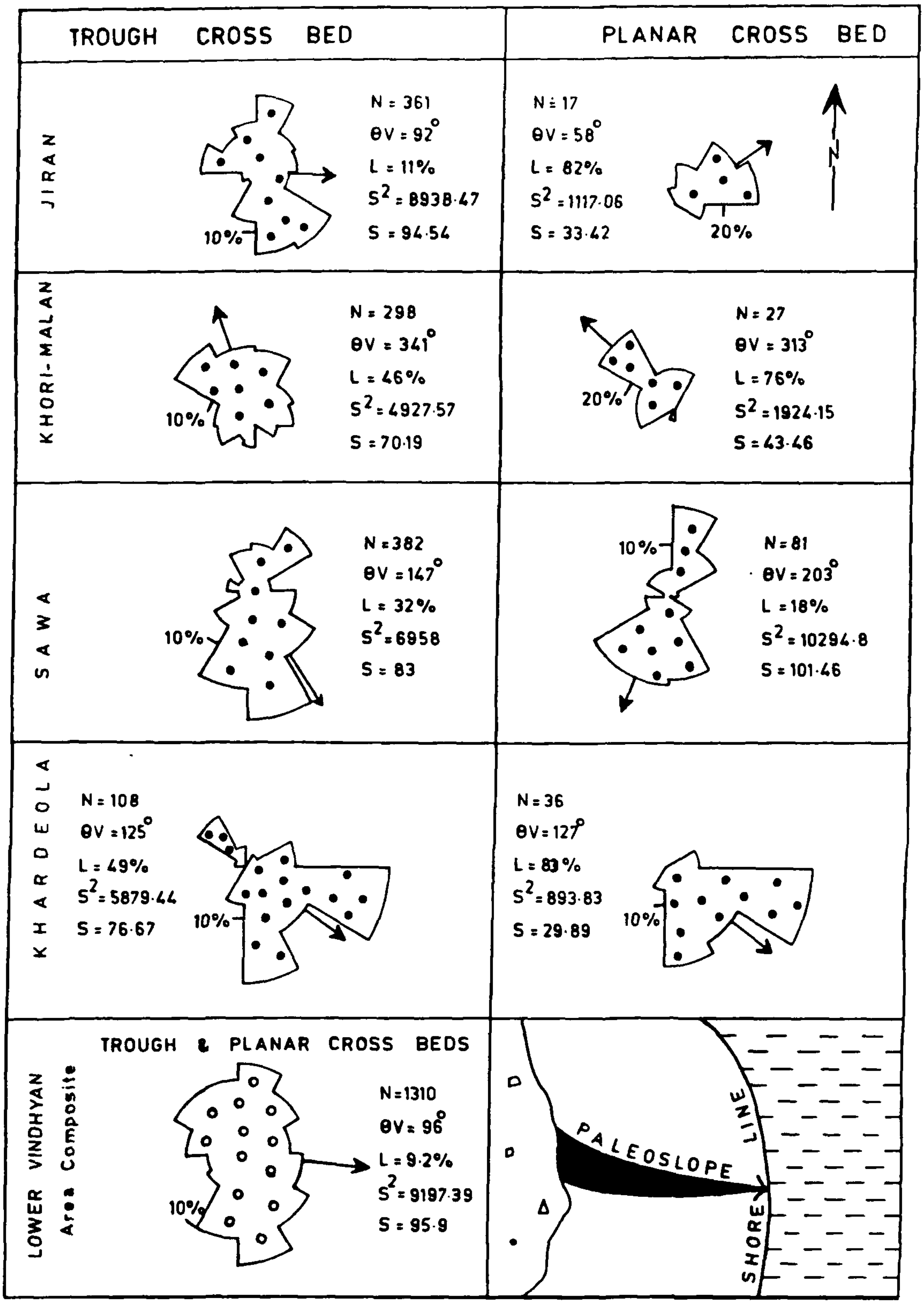

Fig 35 Rose diagrams showing mean paleoflow through time in the various formations of Lower Vindhyan rocks based on composite data from trough and planar cross beddings. Inset shows Area composite for cross bedding of Lower Vindhyan rocks and Middle Proterozoic paleoslope and possible shore line vis-a-vis study area.

Khardeola and Sawa Formations show bimodal paleoflow pattern as principal mode directed toward east and south east with corresponding vector mean toward 127^{o} and 203^{o}. However, Khori-Malan and Jiran Formations show unimodal paleoflow pattern with modal class and grand vector mean are directed toward north west (300-330^{o}) and east (60-90^{o}) respectively (Fig. 35).

Thus it clearly shows that the Middle Proterozoic Lower Vindhyan sediments from Khardeola to Jiran Formations were brought to the basin of deposition largely by multi directional currents characteristics of the coastal environments, which flowed dominantly and inconsistently from north west to south easterly or reverse direction during flood dominated tidal currents particularly during Khori-Malan Sandstone Formation. The multi direction paleocurrent model from base Khardeola to top Jiran Formation may indicate oscillatering basin condition during Lower Vindhyan sedimentation time. The paleocurrent study further reveals that the variance and stand deviation of depositional agency (coastal currents) was high for Khardeola Sandstone ($S^2 = 5879.44$; $S = 76.67$), moderately high for Sawa Sandstone ($S^2 = 6958$; $S = 83.41$), slightly low for Khori-Malan Sandstone ($S^2 = 4927.59$; $S = 70$) and higher still for the Jiran Sandstone ($S^2 = 8938.47$; $S = 94.54$). Pryor (1960, P. 1490) has emphasized that probably the most important factor controlling the variance and standard deviation of dispersal pattern is the amount of slope of the depositional surfaces - greater the amount of slope the smaller the variance and standard deviation. Thus, it is likely that the slope of the depositional basin was gentle during sedimentation of Lower Vindhyan rocks in the study area as it evident by large variance of the system. On the basis of paleoflow analysis through space and time in various formations of Lower Vindhyan rocks based on cross bed azimuth (Fig. 35) clearly indicate that the paleoslope during Lower Vindhyan time was nearly toward east.

CHAPTER VI

PROVENANCE, DEPOSITIONAL ENVIRONMENTS AND PALEOGEOGRAPHY

The ultimate aim of the present investigation is to unfold the sedimentation history of the Lower Vindhyan sediments with special reference to Khardeola, Bhagwanpura, Sawa, Khori-Malan and Jiran Formations of Middle Proterozoic rocks of southeastern Rajasthan. A sedimentary rock is by and large a complex of physical, chemical and biological conditions under which a sediment accumulates (Krumbein and Sloss, 1963) in which the clastic sediments are the residues derived from the pre-existing rocks due to chemical and physical weathering (Pettijohn, 1975, 1984). It recent years there has been increasing interest and emphasis on the synthesis of sedimentary facies, facies assemblage and depositional environments of ancient and recent sediments (Pettijohn, 1975; Reineck and Singh, 1980; Walker, 1984; Reading, 1986; Einsele, 1992; Miall, 1984a, 1993).

One of the aims of sedimentologists is to locate and find out the pre-existing rocks or provenance which provided sediments debris to the transporting agency. The sedimentological evidences collected from lithostratigraphy, facies analysis, petrography and paleoflow analysis are used for understanding the depositional history of the given sediments. Facies analysis, in particular, provides evidence for the reconstruction of environments of deposition and prevailing hydrodynamic processes during the deposition of these sediments. Paleocurrent analysis and petrographic study provide useful evidence in respect of paleoslope and paleodrainage including composition and location of the provenance.

PROVENANCE

The term Provenance is derived from the French word 'Provenir' meaning to originate or to come forth (Pettijohn et al; 1987, P.254). Provenance deals with the climate, relief and the kind of source rock from which the sediment originated. The clastic sediments are basically and fundamentally insoluble residues left after chemical and mechanical break down of pre-existing rock. The composition of the sediment depends in part on the nature of the source rock and in part on its maturity, which is a measure of the extent to which the decompositional processes were carried toward completion. Each type of parent rock tends to provide a characteristic suite of minerals which therefore are a guide to the parent rock. The maturity of sediments is described in terms of the climate and relief of the source area. Therefore, one of the aims of petrographic examination of framework constituents of Sandstone was to find out the probable composition and possible location of the source area, taking into account the evidence from paleoflow study.

According to Folk (1980) classification, about 50% of the studied sandstones are quartz arenite, 25% subarkose, 21% sublitharenite and rest 4% arkose (Table-7). The average detrital composition of the studied sandstone is 48.86% common quartz, 14.76% recycled quartz, 15% cement or matrix, 9.82%

metamorphic quartz, 4.05% vein quartz, 3.86% feldspar, 1.79% volcanic quartz and less than one percent each of heavy mineral, rock fragments and mica.

Evidence from Detrital Quartz

The detrital quartz is both physically and chemically durable and most abundant constituent of framework. It has been used as a useful guide to composition of provenance. In this study quartz types have been recognised and related to source rocks on the basis of shape, texture, extinction and mineral inclusions (Mackie, 1896; Krynine, 1940; Blatt and Christie, 1963; Conolly, 1965; Blatt, 1967; Folk, 1980; Blatt et al, 1980).

Common quartz or monocrystalline quartz, the predominant detrital constituent of the studied sandstone, is not diagnostic of any particular source rock because this variety of quartz is derived from many sources. Mack (1981), on the basis of his study of modern Sands demonstrated that monocrystalline quartz is mainly derived from well sorted sandstone. Sands of metamorphic percentage are also enriched in monocrystalline quartz and feldspar due to mechanical destruction of metamorphic rock fragments (Suttner et al, 1981). The most common sources of common quartz are however believed to be granite and gneisses (Folk, 1980).

The common quartz ranges from 30.45 to 81.65% (average 55.37%) in Khardeola; 47.46 to 54.41% (average 51%) in Bhagwanpura; 3.75 to 80.55% (average 41.96%) in Sawa; 1.07 to 71.70% (average 42.06%) in Khori-Malan and 1 to 88% (average

58.54%) in Jiran Sandstones (Appendix-III).

Reworked sedimentary quartz with abraded overgrowth is next to common quartz, forms 1 to 29% (average 10%) in Khardeola Sandstone; 0.0 to 23.73% (average 11.86%) in Bhagwanpura Sandstone; 1 to 71% (average 22.18%) in Sawa; 1.8 to 71.66% (average 22.6%) in Khori-Malan and 0.0 to 10.19% (average 1.67%) in Jiran Sandstones.

Metamorphic quartz ranges from 0.0 to 35.0% (average 7.42%) in Khardeola Sandstone; 0.0 to 12.5% (average 6.25%) in Bhagwanpura Sandstone; 1.85 to 38.8% (average 10.8%) in Sawa Sandstone; 0.0 to 39.3% (average 12.70%) in Khori-Malan and 0.0 to 31.15% (average 7.97%) in Jiran Sandstones (Appendix-III).

This implies that granitoid and sedimentary rocks were the main source of quartz in all the formations followed by metamorphic including metasedimentary rocks. Minor sources comprises pegmatites/hydrothermal veins that yielded vein quartz, which averaging 4% of the total detritus of the framework in all the sandstones.

Evidence from Feldspar

The potassic varieties of feldspar including orthoclase and microcline are more than plagioclase. The altered orthoclase and microcline are more common. Excess of quartz over feldspar and orthoclase over plagioclase may indicate greater weathering in sources area and/or greater abrasion of sediment during transport (Pettijohn et al; 1972, P.307). The total feldspar in different formations varies from 1.0 to

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8.49% (average 3.25%) in Khardeola; 1.47 to 3.39% (average 2.43%) in Bhagwanpura and 1.85 to 24.51% (average 8.72%) in Sawa Sandstones while feldspar in Khori-Malan and Jiran Sandstones is less than 1% or almost negligible. Thus feldspar types (orthoclase, microcline, plagioclose) and relative abundance of each type (orthoclase > microcline > plagioclose) indicate a source comprising acid plutonic rock and gneisses for Khardeola, Bhagwanpura and Sawa Formations. However little or no feldspar in Khori-Malan and Jiran Formations indicate that little or no feldspar was available in the source area. Schist, phyllites, slates or older sediments contribute little or no feldspar and may be source for Khori-Malan and Jiran Sandstones.

Evidence from Heavy minerals

Heavy minerals have long been used as guide to the composition of the source rocks (Krumbein and Pettijohn, 1938, Pettijohn, 1975). The heavy mineral suit of the Middle Proterozic sediments of study area contains in particular as tourmaline, zircon and opaques.

Prismatic, angular to rounded, brown and yellow coloured tourmaline are more common than zircon in Khori-Malan and Jiran sediments. The well rounded tourmaline may suggest long transportation from source rocks or derivation from pre-existing sedimentary rocks. However brown and yellow varieties of tourmaline are believed to be derived from pegmatite rocks (Blatt et al, 1980).

Non pleochroic, colourless, prismatic and rounded zircons are more common in Khardeola and Sawa sediments than Khori-Malan and Jiran sediments. The euhedral zircons are thought to be derived from acid to intermediate igneous rocks. Euhedral zircons may have been derived from crystalline source rocks (Smithson, 1939; Iijima, 1959; Okada, 1961). The zircon suit of the studied sediments may have been derived from acidic plutonic rocks and metasediments or pre-existing sediments.

Evidence from Rock Fragments

Rock fragments in sediment are among the most informative of all detrital components and of utmost importance in diagonsing and determining the provenance composition. They occur up to 2.85% in Khardeola, 2.26% in Bhagwanpura, 1.37% in Sawa, 4% in Khori-Malan and 1.48% in Jiran Sandstones. The rock fragments is consists of chert, siltstone, shale, quartzite, quartz schist and granite. Sedimentary rock fragments is being more dominant among other fragments. The fragments of sedimentary rocks are generally not resistant to abrasion and so a large part of this was probably destroyed during transportation or reworking. This indicate mixture of sedimentary and metamorphic rocks in the source area.

Evidence from Pre-existing sedimentary rocks

Evidence for pre-existing sedimentary rocks is derived mainly from the occurrence of rounded to well rounded stable dterital components, particularly tourmaline, zircon and sand size grains of quartz and chert showing abraded overgrowth.

Although the rounded detrital grains, referred to above occur sporadically in the studied sediments, their association with subangular to subrounded feldspar and other grains of similar composition is anomalous and can best be explained by visualising their derivation as second cycle from older sedimentary rocks.

Evidence from Detrital mica

Detrital mica occurs in small proportion of which muscovite exceeds biotite (Appendix-III). Folk (1980) believed that greater source of muscovite is in the pegmatite rocks.

Evidence from embedded pebbles

The embedded pebbles occurs in Bhagwanpura, Sawa and Khori-Malan Formations, are subangular to subrounded and consist of quartz, chert, quartzite, feldspar and granite. They are more mature in composition in the Sawa Formation. Some pebbles are subrounded to rounded, possibly due to long transport or prolonged abrasion which eliminate unstable and metastable rocks fragments from the resultant sediments.

From the combined evidence of composition of lighter minerals, pebbles, sand sized rock fragments, heavy minerals and Qt-F-L and Qm-F-Lt plots of studied sandstones as per Dickinson classification (1985); it is summarised that the sediments were largely derived from a mixed source of acid plutonic to intermediate igneous rocks, meta sedimentary and sedimentary rocks. The sand sized detrital metamorphic quartz (recrystallised and stretched), vein quartz and rounded heavy mineral species indicate that schist, phyllite, slate and pegmatite rocks have also contributed sediments to present rocks.

Dispersal Pattern, composition and location of Provenance

Figure 36 is a schematic map showing the dominant dispersal pattern of Middle Proterozic sediments of western Vindhyan basin, based on Paleocurrent studies described earlier (Fig. 35) and composition and location of Bhilwara supergroup, Berach granite and Bhadesar quartzite in and around Middle proterozoic basin. The uniformity and consistency of south easterly directed paleoflow through time clearly postulate that the interfering coastal current systems (flood, ebb, longshore and rip currents) maintained paleoslope from north-west to south east though out course of sedimentation in the study area.

Evidently, the bulk of the quartz pebbles and detrital quartz of igneous and metamorphic origin including K-feldspar and lithic fragments of quartzite, phyllite and slate may have been derived from Bhilwara supergroup, Berach granite and Bhadesar quartzite. Likewise rounded to subrounded sedimentary quartz & vein quartz may have their derivation from metasedimentary and pegmatite rock of Bhilwara supergroup. Heavy minerals species like zircon and tourmaline may have been derived from pegmatite and Berach granite.

Indeed the bimodal paleoflow study conclusively indicates that the main water shed of the Middle proterozoic coastal currents was situated northwest, west and south west

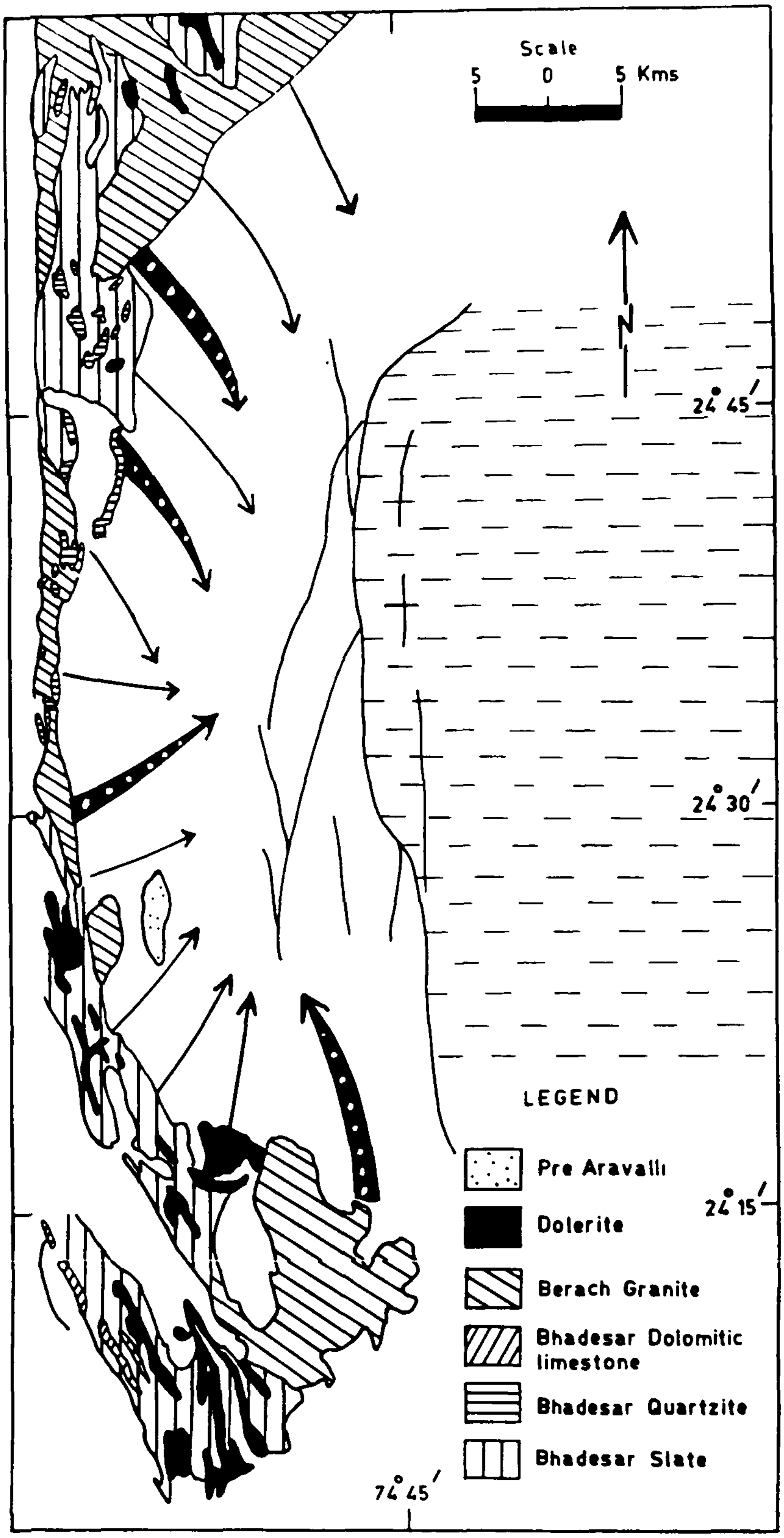


Fig 36 Map showing location of provenance of Lower Vindhyan sediments and the present day distribution of Bhadesar Quartzite, Slate, Dolomitic limestone; Berach Granite and Dolerite of Pre-Aravalli (Bhilwara supergroup) rocks and overall paleogeography and position of shoreline during Lower Vindhyan time.

of the Vindhyan basin, represent by high lands of quartzite, schist and phyllite.

The igneous and metasedimentary rocks of the Bhilwara supergroup, Berach granite and Bhadesar quartzite occur adjacent to Middle proterozoic rocks in the west of the study area as shown in the map in Figure 36. These rocks are the source rock which admittedly provided the great bulk of the sediments to Middle proterozoic Vindhyan basin of Rajasthan.

D E P O S I T I O N A L   E N V I R O N M E N T S

The heterogeneous assemblage of sandstone, shale, limestone and interbeds of conglomerate constituting the Lower Vindhyan sequence of the area under study exhibits facies association and sediment character similar to those which characterised coastal environments including Barrier beachs, shoreface, foreshore, tidal channels, tidal inlet, intertidal lagoons. The coastal environment for these sediments was assigned by early workers (Prasad, 1975, 1984; Singh, 1980; Chandra and Bhattacharya, 1982).

The sedimentary facies of the Lower Vindhyan sequence described and illustrated earlier (Chapter-II), include cross-bedded sandstone bodies throughout the sequence which were analysed quantitatively to determine paleoflow and paleoslope of the depositional system. Evidence from sedimentary facies, their vertical relationships and environmental interpretation for each formation, as summarised in columnar diagrams in Figures 37 to 45 form the basis for reconstructing the depositional domain of the Middle

Proterozoic sequence of Bhadesar - Nimbahera area.

KHARDEOLA FORMATION

A generalized facies model of the basal Khardeola Formation is shown in Figure 37 based on a number of outcrop sections in the study area. The facies model consists of recurring coarsening upward cycle averaging 30m in thickness. Each lithofacies in terms of its code, sedimentary characters viz. colour, grain size, sedimentary structures and environmental interpretation is illustarated in the facies model (Fig. 37). The dominant facies recognised in the Khardeola Sandstone in the study area are as follows :

	Facies	Environmental Interpretation
St	- Trough cross bedded sandstone	Shoreface to foreshore
Sp	- Planar cross bedded sandstone	
Sm	- Massive sandstone	
Sh	- Horizontal bedded to laminated sandstone	
Fl	- Laminated siltstone to shale	Back Barrier

The major facies of coarsening upward cycles are represented by trough and planar cross bedded sandstone (St or Sp) bodies in the middle to upper part and laminated siltstone facies in the lower part. The overall lithofacies association, *poorly coarsening upward character of the assemblage and grain* size analysis plus the dominant unimodal to bimodal

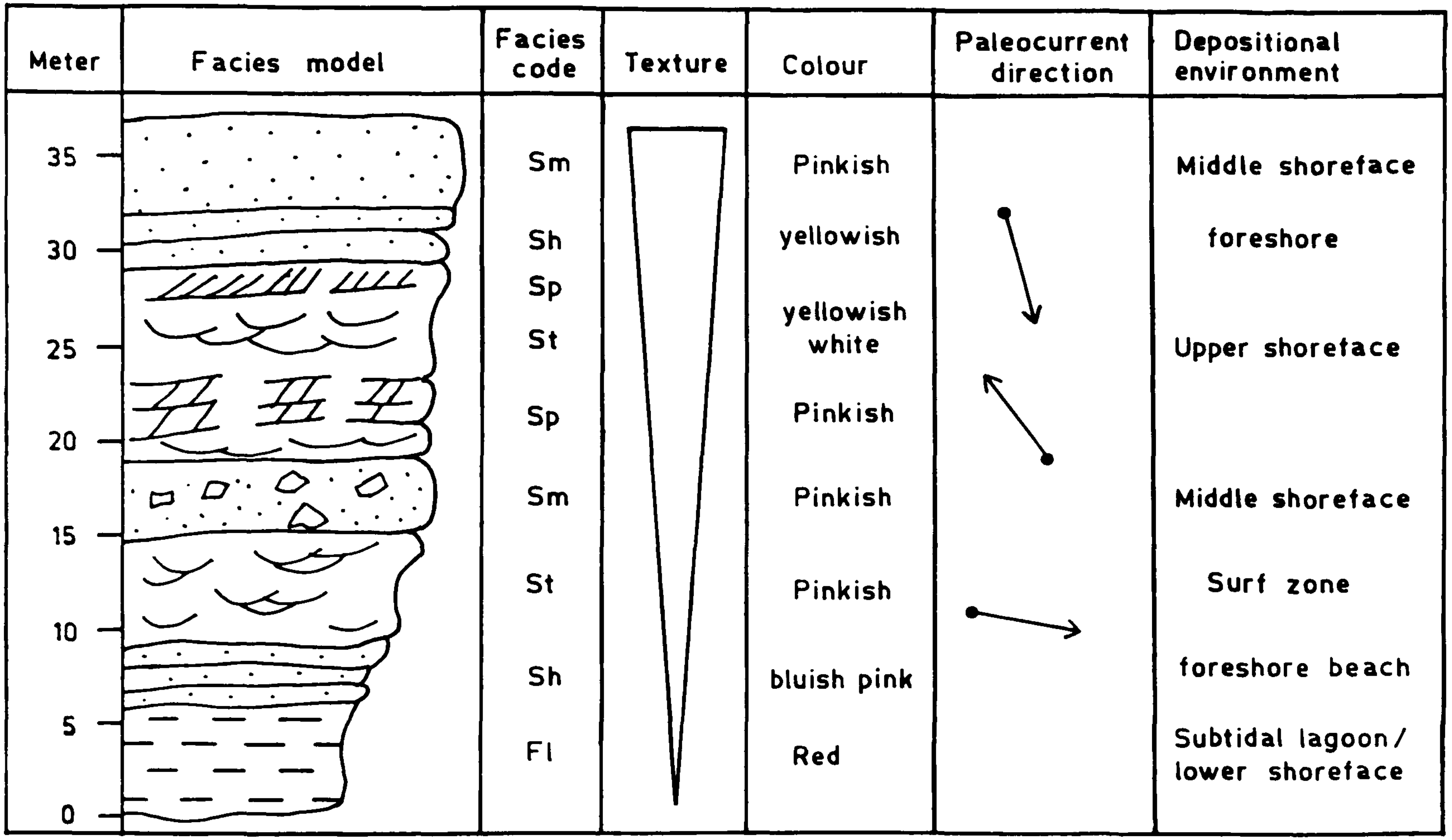


Fig. 37 Generalized Facies model is showing commonly occurring vertical transition of different facies in the Khardeola Sandstone Formation. Probable depositional environments are listed alongside. Explanation for facies code is described in Chapter - II.

paleocurrent directed toward open sea in the south-east of the study area clearly postulate a shoreface to foreshore environment, the intermittent Barrier Beach/Back Barrier (lagoon) influence is particularly evident in the lower part of the formation.

The major and minor depositional environments of Khardeola Formation described here under and diagrammatically picturized in Figure 37.

Trough and planar cross-bedded sandstone (St and Sp) facies

The St or Sp facies overlies Sh or Sm facies and comprises pinkish to yellowish white, fine to medium grained, moderately well sorted sandstone. Dominant sedimentary structures include large scale planar and trough cross bedding. The cross strata show unimodal to bimodal distribution or at places trimodal (Fig. 24 to 26) and dip predominantly Southeast or North-east. This facies is characterized by abundant evidence for tractive currents. The presence of large scale cross bedding and polymodal distribution of cross beds and variable texture indicate that St or Sp facies were deposited within the zone of breaking waves or surf zone of upper shoreface environment (Reinson, 1984; Clifton et al, 1971; Decelles, 1987; Einsele, 1992). The upper shoreface environments corresponding to the upper part of the surf zone are dominated by powerful onshore, offshore and longshore currents. The predominant South-east ward dipping directions of cross beds in facies (St or Sp) reflect a dominance of shoreward-driven paleocurrent.

Horizontal to parallel laminated sandstone (Sh) facies

The (Sh) facies truncates St or Sp or Sm facies along a sharp, roughly horizontal contact. A sharp break in sorting and grain size occurs at the facies boundary, between the relatively poor sorted, medium grained facies (Sm) and the well sorted, fine grained sandstone of Sh facies. The horizontal and parallel laminated sandstone are characteristic of inner planar facies of swash zone of foreshore beach environment (Hunter et al, 1979; Reinson, 1982; Decelles, 1987; Einsele, 1992). Clifton et al (1971) found this facies on the non-barred beaches of southern Oregon.

Massive sandstone (Sm) facies

The Sm facies occurs in the middle and upper part in the Khardeola sequence represent interbedded with Sp, St or Sh facies and comprises thick bedded, pinkish, moderately well sorted sandstone. This massive sandstone is devoid of all internal structure and contain interbeds of volcanic clastic sediments (v.breccias) as give the evidence that Khardeola Sandstone is syndepositional with Kharimalia (volcanic) flows. The massive and thick bedded nature of sandstone indicates that Sm may probably deposited during middle shoreface (Galloway and Hobday, 1983).

Laminated siltstone to shale (Fl) facies

The Fl facies truncates (Sh) facies along a sharp, roughly horizontal contact in the lower part of the Khardeola Formation. The fine to very fine grained sands with intercalated layers of silt of this facies implies low energetic conditions that in any of the overlying facies, may represent lower shoreface/offshore condition of deposition (Harms et al, 1975; Walker, 1984; Reinson, 1984).

BHAGWANPURA FORMATION

A generalized facies model of the succeeding Bhawanpura Formation is shown in Figure - 38 based on a number of outcrops sections in the study area. The facies model consists mainly of limestone cycle with thinner cycles of shale and sandstone. Each lithofacies in terms of its code, sedimentary viz. colour, grain size, sedimentary structures and environment interpretation is illustrated in the facies model. The dominant facies recognised in the Bhagwanpura Formation in the study area are as follows :

Facies	**Environmental Interpretation**
Lithofacies A	Subtidal lagoon
Lithofacies B	Intertidal to
Lithofacies C	supratidal zone
Sl-Fl Interbedded sandstone and shale	High intertidal flats
Sm - Massive sandstone	Intertidal sand bar
Fsc - Calcareous shale	Subtidal lagoon

The major facies are presented by lithofacies A, B and C in the upper and middle part and calcareous shale, interbedded sandstone to shale and massive sandstone in the lower part. The overall lithofacies association and

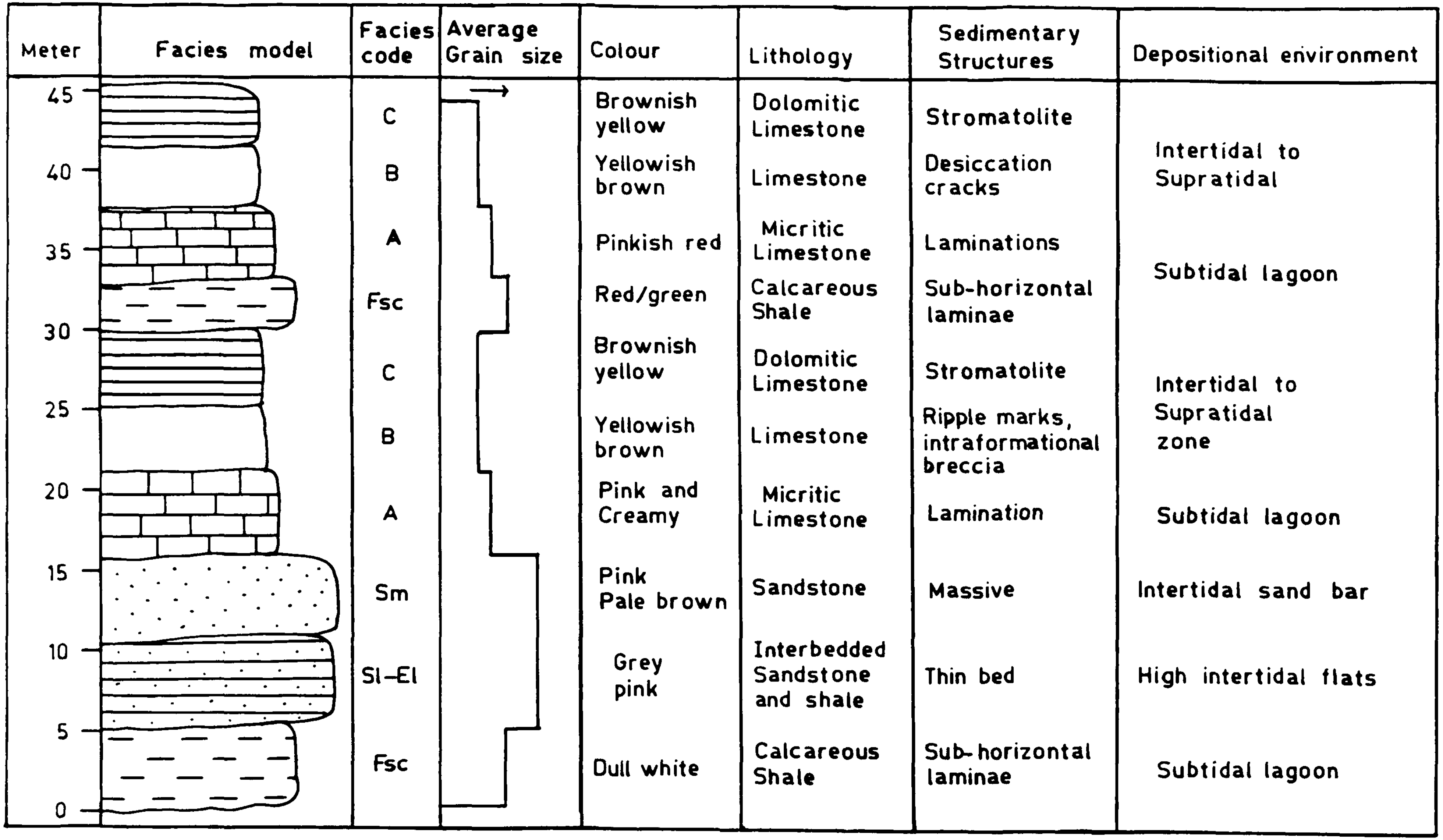


Fig. 38 Generalized Facies model is showing commonly occurring different facies with probable depositional environments in the Bhagwanpura Limestone Formation.

petrographic character of the assemblage represent that Bhagwanpura Formation may be formed in a protected low energy sea marginal environment comprising tidal flats and a shallow subtidal lagoon (Back Barrier).

Lithofacies A

Lithofacies A truncates lithofacies B or C along a sharp roughly horizontal contact in middle part of the Bhagwanpura Formation. Lithofacies A is characterized by micritic to dolomitic limestone and consist of laminated, horizontal to wavy bedded pink limestone.

Micrite is generally forms in area of ineffective winnowing and calm waters (Folk, 1980). Abundance of micrite in this facies may be suggestive of a subtidal environment, where the current action was not strong enough to winnow out the micrite.

The parallel lamination and micritic composition of the limestone together with the absence of any evidence, suggestive of strong wave action or subaerial exposures, imply that the pink limestone might have been deposited in a low energy subtidal lagoon environment (Rao et al, 1981). The lack of sedimentary structures in this micritic limestone lithofacies may suggests deposition in a deeper subtidal setting that was not colonized by algal mats (Myrow and Landing, 1992).

Lithofacies B

Lithofacies B is characterised by well developed ripple marks, intraformational breccia, desiccation cracks. The limestone is yellowish brown to blackish, siliceous and dolomitic in composition and contain appreciable terrigenous quartz grains and Bird's eye or fenestrae structure in microfacies. Ripple marks are suggestive of deposition in shallow waters while intraformational breccia and mud cracks are evidences of subaerial exposure of the sediments. The intraformational breccia is being produced in the high intertidal zone and predominate in the lower supratidal zone (Blatt et al, 1972; Wright, 1992). Tidal flats and tidal channels have been considered to be most favourable sites for the accumulation of intraformational breccias (Soderman and Carozzi, 1963; Jindrich, 1969). The association of intraformational breccia with cross lamination and ripple marks is considered to be diagnostic of the intertidal environment (Braun and Friedman, 1969). Bird's eye and fenestrae in silty carbonates are most commonly indicative of upper intertidal to supratidal environment (Wolf, 1965; Shinn et al, 1969; Shinn, 1983). Thus abundance of structure such as ripple marks, intraformational breccia, desiccation cracks, Birds eye or fenestrae and presence of terrigenous material such as sand size detrital quartz, quartzite, chert and calcite grain may suggest that lithofacies B may be deposited into intertidal to supratidal environment.

Lithofacies C

Lithofacies C is overlain or underlain by lithofacies A and B characterised throughout the area by yellowish brown to blackish brown stromatolite. The rock is limestone which is siliceous and dolomitic in composition. The following stromatolites groups have been identified among the columnar stromatolites after Prasad (1976, 1978, 1980), Raja Rao and Mahajan (1965), Barman and Verma (1980) : (a) Colonella, (b) Kussiella, (c) Conophyton and (d) Weedia.

The non columnar types which are more frequent than the columnar types are laminated, broken ripple like structures and correspond to the LLH-C and LLH-S types of Logan et al (1964). The ripple like structures in cross sections appear as broad elliptical and circular bodies. They are composed of a number of concentric circular or elliptical rings.

The ripple like stromatolites (LLH-C and LLH-S) and columnar stromatolites like Bicalia, Colonella, Kussiella etc. (SH-V), the former being suggestive of protected intertidal mud flat and the latter exposed intertidal conditions, are noticed in the limestone. The ripple like domal stromatolites of smaller dimensions are considered by Truswell and Erikson (1973) as suggestive of shallow subtidal zone. Serebyakov and Semikhatov (1974, P. 534) also described that many ancient (Precambrian) stromatolites including the most Riphean ones, were formed under subtidal conditions. So, it is possible that the stromatolitic horizons of yellowish brown limestone may be shallow subtidal interlayered with non-stromatolitic limestone of intertidal origin. Stromatolites deposits may also accumulated in a long persisting subtidal, intertidal and supratidal environment reflect very stable tectonic and environmental conditions (Song and Gao, 1985; Einsele, 1992). This facies under microscope shows Bird's eye or fenestrae structure and contains silty micrite, intramicrite and dolomitized micrite with abundance of terrigeneous material.

Bird's eye or fenestrae structures are reported to be highly characterstic of upper intertidal to supratidal environments (Shinn, 1983; Minero, 1991; Wright, 1992).

Microfacies analysis, abundance of stromatolite and fenestrae structure and terrigeneous admixutre may suggest that lithofacies C may be deposited into intertidal and supratidal environments and reflect stable tectonic and environmental conditions.

Interbedded sandstone and shale (Sl-Fl) facies

The Sl-Fl facies (average thickness 12m) occupies the lower part of Bhagwanpura Limestone Formation. The dominant processes of sedimentation affecting deposition of these rocks are believed to have been, in order of decreasing importance, alternating tidal current bed load transport, tidal scour and slack-water suspension settling. The sedimentologic and lithologic attributes of this facies, are interbedded feldspathic siltstones or siltstone and shale, are analogous to those of the lower parts of modern high intertidal flats (Klein, 1967a,1970 b, 1971; Kuijpers, 1970 and 1971; Reineck, 1967; Mazzullo, 1978). These interbedded rocks are believed to have been deposited in the lower most intertidal zone : the silts were deposited by high energy tidal current bed load traction whereas the shale represent suspended particles that settled out during slack water periods.

Massive Sandstone (Sm) facies

The Sm facies are consists of brownish grey to grey, well to moderately well sorted and rounded, fine to medium grained sandstone. This facies is overlain and underlain by lithofacies B (intraformational breccia) and Sl-Fl facies respectively. The sandstone is compositionally quartz arenite to feldspatic and thick to massive bedded. The massive sandstone may be due to the destruction of original lamination or by physical disruption due to liquefaction and movement of the sediment while it was still in a waterlogged state. Lack of lamination or massive can also imply rapid deposition from suspension, most probably by the deceleration of a heavily sediment-laden current (Collinson & Thompson, 1982). Massive bedded sandstone with asymmetric wavy surface undulations suggest tractional current tidal flow under the lower flow regime (Klein, 1970 b). This facies may represent upper subtidal to lower intertidal environment (Mazzullo, 1978; Klein, 1985).

Calcareous shale (Fsc) facies

Red and green coloured calcareous shale, the main constituent of this lithofacies represent suspension deposits of a low-energy environment (subtidal) is evidenced by their parallel lamination and general absence of current and wave formed structures (Reinson, 1984; Boothroyd, 1985).

SAWA FORMATION

A generalised facies model of the Sawa Formation of sand group is shown in Figure 39 based on a number of outcrop sections in the study area. The Sawa Formation is divided into three parts. The facies model show progradational coarsening upward cycle in the lower to middle part and locally fining

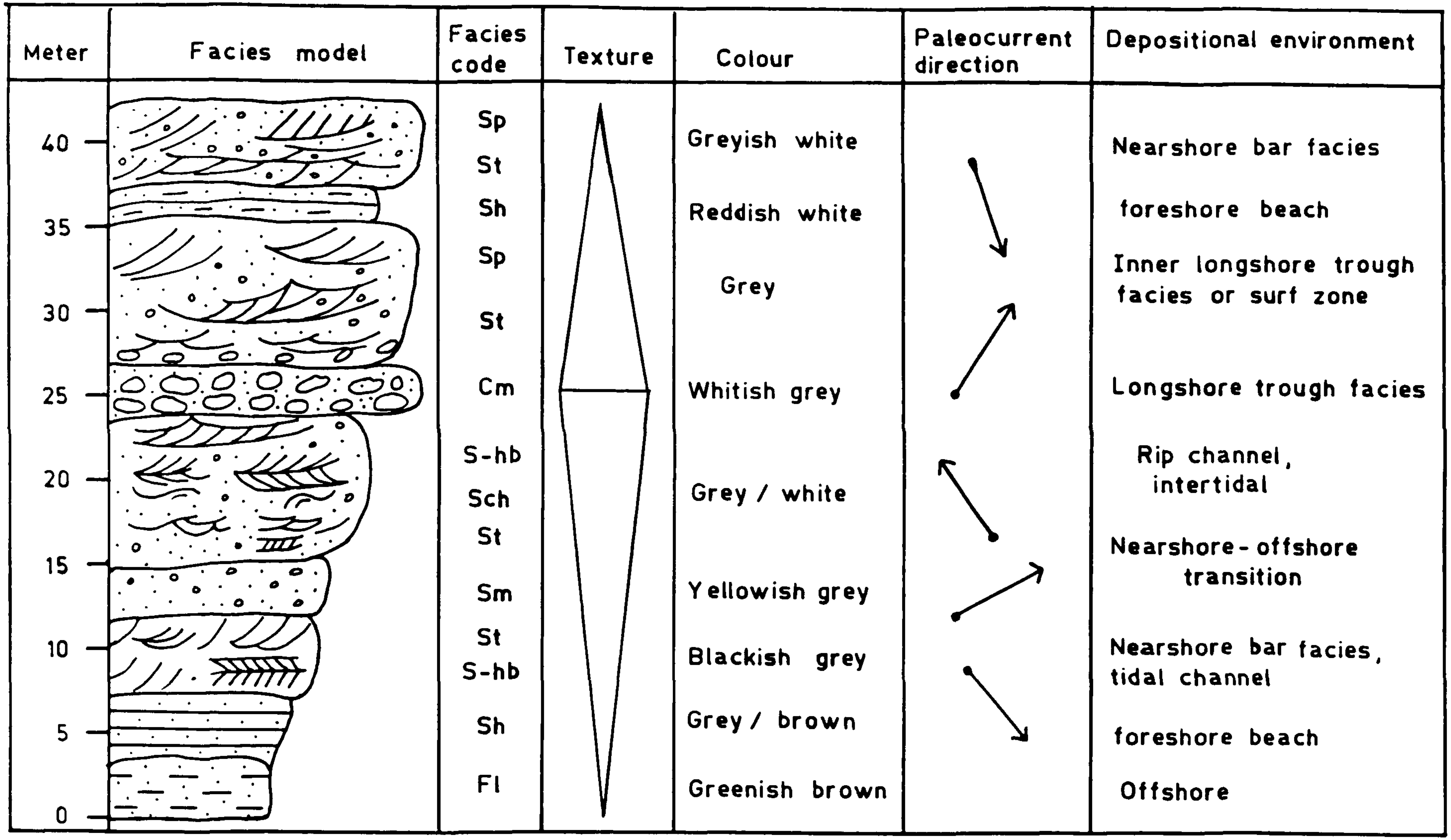


Fig. 39 Generalized Facies model is showing vertical transition of different facies in the Sawa Sandstone Formation. Computed paleocurrents and probable depositional environments are listed alongside.

upward cycle in the upper part of the Sawa sequence. Each lithofacies in terms of its code, sedimentary character. viz; colour, grain size, sedimentary structures and environmental interpretation is illustrated in the facies model (Fig. 39). The dominant facies recognised in the Sawa Formation in the study area are as follows :

Facies	**Environmental Interpretation**
St - Trough cross bedded sandstone Sp - Planar cross bedded sandstone Sm - Massive sandstone Sh - Horizontal bedded to laminated inclined sandstone Fl - Laminated siltstone to shale	Oblique Bar-Rip Channel/Non barred Nearshore system
Cm - Massive conglomerate	Longshore trough and rip channel facies
S-hb - Herringbone cross bedded sandstone Sch - Channel sandstone	Tidal channel or Tidal flat

The major facies of oblique bar-rip channel system are represented by trough and planar cross bedded sandstone bodies in through out the sequence and massive and horizontal to laminated inclined sandstone interbedded with St or Sp facies. The over all lithofacies association, coarsening upward sequence, grain size analysis and the dominant bimodal and occasional unimodal paleocurrents directed toward southeasterly, clearly indicate that Sawa sequence may represent a oblique bar-rip channel nearshore (Hunter et al, 1979; Davis, 1985) or non-barred nearshore (Clifton et al, 1971; Davis, 1985; Einsele, 1992) with the intermittent tidal influence is particularly evident in middle part of the formation.

The major and minor depositional environments of Sawa Foarmation are described here under and diagrammatically picturised in Figure 39.

Sandstone Bodies : Oblique bar-rip channel or Non-barred Nearshore system.

Detailed study of the sandstone bodies has been augmented by a through measured stratigraphic records, to provide a more generalised view of distribution of sandstone facies. Sandstone is ash grey to pink and commonly medium to coarse grained. The sandstone bodies are highly cross bedded, horizontal to inclined bedded and locally massive and less than 10 to 40m in thickness, depending upon thickness of the cycle.

Trough cross bedded sandstone facies (St), coarse to medium grained, moderately well sorted and generally has an erosional base with individual cross bedded sets about 30cm to 0.5m thick. This facies is profusely developed in Sawa Formation through out the area, generally occuring in the middle and upper part of the sequence. Trough cross bedded sandstone facies is produced mostly by the migration of lunate mega ripples (Hunter et al, 1979; Davis, 1985; Einsele, 1992). The coalescing sandstone bodies characterised by St facies, may be attributed to have formed possibly by migration of lunate megaripples in bar, longshore trough and rip channel facies of oblique Bar-Rip channel system (Hunter et al, 1979) or surf zone of Nearshore (Clifton et al, 1971; Reinson, 1984, Decelles, 1987; Einsele, 1992). Foreset dip azimuth of St facies in Sawa sequence show unimodal to bimodal orientation and directed commonly toward southeast, east, northeast indicating that the depositing current system flowed seaward i.e. southeast, east and northeast of the area.

Likewise, planar cross bedded sandstone (Sp) facies, often interbedded with St facies may have resulted from the migration of linear mega ripples and sand waves (Harms and Fahnestock, 1965; Boothroyd, 1985; P. 472). The planar cross bedded sandstone bodies exhibiting bimodal orientation with principal and subsidary modes respectively toward southeastward and northeastward may be attributed to migration of longshore bar, Rip channel bar in offshore system (Clifton et al, 1971, Hunter et al, 1979; Davis, 1985; Decelles, 1987; Einsele, 1992).

Conglomerate (Cm) facies

The conglomerate facies containing clasts of pebble to cobble size, ranging from about 1 to 8cm in diameter, the clasts are subangular to subrounded, although rounded clasts may also occur. This facies overlain and underlain by coarse to medium grained, cross bedded sandstone as much as about 8m thick. The sandstone is moderately sorted and pebbles can be scattered through the sand or sharply segregated into thin, persistent beds which rest upon gently inclined erosion surfaces. Pebbles imbrication in these layers is poor, but axes tend to be inclined to the east (seaward). Bedding within this zone is either high-angle, trough cross beds or horizontal or nearby horizontal bedding. The sets of trough cross bedding range in thickness from 15cm to 1.5m and cross bed dips are predominantly to the east (seaward), although a less common secondary mode directed toward the south (parallel to shoreline) also exists. In this overall association the conglomerate facies may probably deposited within the area of wave build up and surf zone where rip and longshore currents continuously rework and sort the sediment (Harms et al, 1975).

The various sedimentary structures and grain size in this facies reflects complex interaction of oscillatory and undirectional currents, a charactristic of modern longshore trough and rip channel subenvironments (Davidson-Arnott and Greenwood, 1976; Hunter et al, 1979; Greenwood and Davidson-Arnott, 1979; Greenwood and Sherman, 1984, 1986; Short, 1984; Decelles, 1987 and Einsele, 1992). The abundance of large scale trough cross bedding in this facies suggests that unidirectional, shoreparallel to oblique offshore currents prevailed over oscillatory wave induced currents.

Beach Foreshore deposits

The horizontal bedded to inclined laminated sandstone (Sh) facies truncates facies St or Sp, Cm or Fl along a sharp, roughly horizontal contact. Dominant sedimentary structures are horizontal, inclined and laminated bedding clearly indicate Beach foreshore deposit (Decelles, 1987) or Inner plannar facies of oblique bar-rip channel system (Hunter et al, 1979; Einsele, 1992). The local trough cross bedded units probably were formed by small runoff channels on the upper beach (Decelles, 1987). Occasional interbeds of massive sandstone may suggest deposition in shallow water (Willis et al, 1972; Smith, 1971) and Middle Shoreface (Reinson, 1984) or else by erosion of underlying bars under upper flow regime (Harms and Fahnestock, 1965).

Fine clastic (Siltstone, shale and fine grained sandstone)

The Fl facies which merges transitionally with that above (Sh) is thin bedded, finegrained sandstone and siltstone. The fine grained size of this facies implies less energetic conditions than in any of the overlying facies may represent offshore condition of deposition (Walker, 1984).

Evidence of Herringbone cross bedding (S-hb) and channel structure (Sch)

The middle part of Sawa sequence is characterised by grey, coarse to medium grained sandstone and poorly show herringbone cross bedding and channel structure. Presençe of herringbone cross bedding is generally interpreted as reversal of tidal currents (Klein, 1971, 1985; Reading, 1978, P. 235; Leekie and Walker, 1982; Reinson, 1984, P. 127; Davis, 1985; Einsele, 1992). Cross bedding directions in this facies are oppose variably with unequal bipolar-bimodal paleocurrent modes (e.g. $135^{o} \pm 45^{o}$ and $309^{o} \pm 51^{o}$; $24^{o} \pm 36$ and $193^{o} \pm 57^{o}$) indicating that during the deposition of S-hb facies, seaward and landward directed tidal currents (ebb and flood currents) were active in producing the bidirectional cross bedding. Reading (1978, P. 235) attributed the herringbone type of sedimentary structures in sandstone bodies as a diagnostic feature of tidal currents or excellent indicator of reversing or bidirectional flow in estuaries (Boothtoyd, 1985).

The channel facies of Sawa Sandstone may indicate intertidal condition of deposition (Ginsberg, 1975) where alternating erosion and deposition occur due to rapid changes in current or wave velocity.

PALRI FORMATION

A generalised facies model of the Palri Formation of sand group is shown in Figure 40 based on a number of outcrop sections.

The most common lithologies in the Palri Formation is laminated siltstone to shale (Fl) facies with porcellanite bed occur in the lower part of the formation.

The porcellanite bed (Pyroclastic rock) consists predominantly of pyroclastic debris and chert beds and is divisible into the following three rather unequal lithological subdivisions in the ascending order : agglomerates, bedded cherts and banded porcellanite. The "banded" porcellanite is the thickest unit and most conspicuous of the above three subdivisions and consists of alternating black and white bands of very uniform thickness. The black bands are cherty but in thin sections are seen to be composed of Welded rhyolitic tuffs with abundant collapsed pumice lapilli while the white

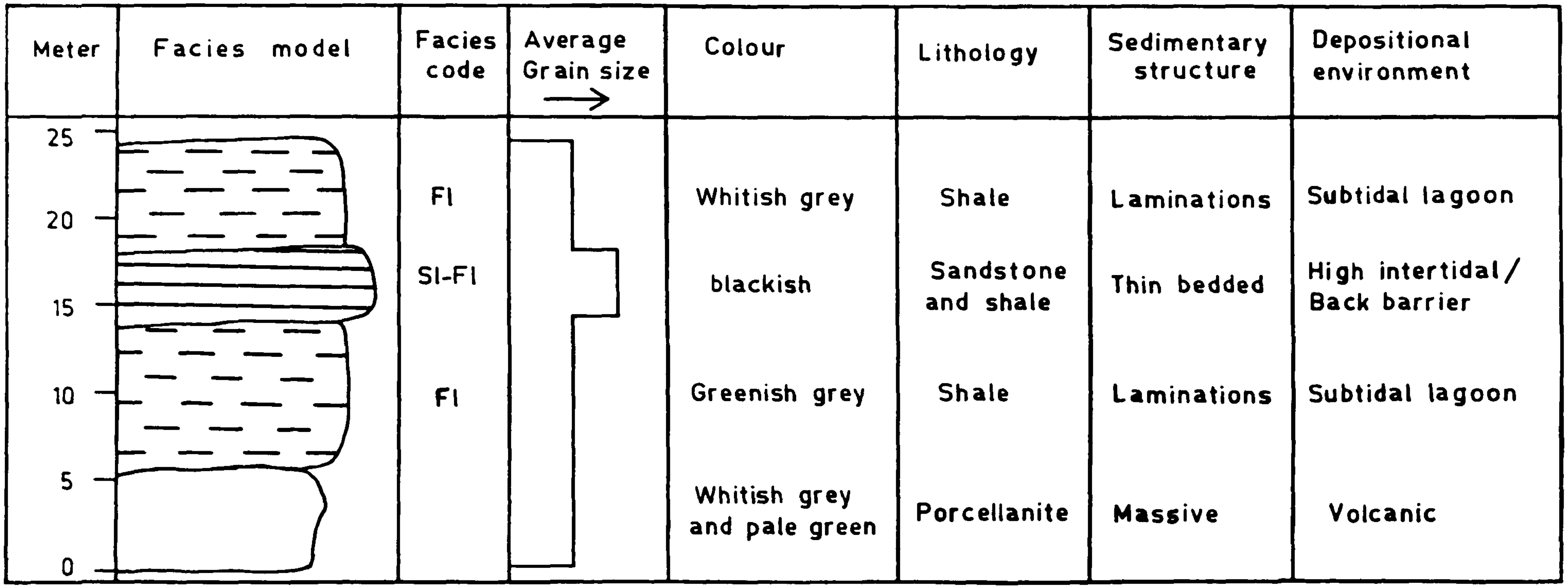


Fig. 40 Generalized facies model of Palri Shale Formation.

bands are made up of very fine volcanic crystal ash (bentonite) in which angular grains of quartz, feldspar and pumice lapilli are embedded. The most characteristics feature of the banded porcellanites are textural and compositional homogeneity and their perfectly bedded nature with uniformity and persistence of thickness of individual beds. The black tuffaceous layers of the banded porcellanite may be related to that phase of volcanic eruption in which the lava froth was forcefully ejected and was intimately disseminated in the atmosphere. The pyroclastic debris therefore is entirely consists of ash and lava froth blow outs and each episode of explosion supplied compositionally and texturally homogeneous but immature dense clouds of pyroclastics which spread out over vast areas and produced, on deposition alternating layers of white crystal ash and black welded vitric tuffs.

Pettijohn (1950) has gave his views regarding origin of pyroclastic rock (Porecellanites) that ash clouds are surcharged with debris and behave like a concentrated aerosol, they will roll down on land as nuees ardentes and give rise to welded tuffs or ignimbrites, but if the mixture of ash and air is dilute, the debris simply, settles down from normal air currents giving rise to bedded tuffs and ash. It is also possible that the above materials may fall in a body of water and get deposited as tuffaceous sandstones and shales. It is possible that the original material from which the porcellanites were derived was almost entirely of pyroclastic origin and that the variations now existing reflect the different physical conditions under which the debris was deposited (Srivastava, 1977).

The Fl facies comprises withish grey to pale green shale interbedded with very fine grained black porcellanite bed. The shale with porcellanite show a general quiet water condition. The Fl facies are believed to have been deposited in the subtidal lagoon environments (Reinson, 1984). The siltstone were transported by high energy tidal current bed load traction whereas the shale represent suspended particles that settled out during slack water periods (Mazzullo, 1978; Boothroyd, 1985).

The overall lithofacies association and petrographic character of the assemblage represent that Palri Formation may be formed in subtidal lagoon (Back Barrier) environment (Mazzullo, 1978; Boothroyd, 1985).

KALMIA SANDSTONE FORMATION

A generalised facies model of the Kalmia Formation of Lasravan Group is shown in Figure 41(A) based on a exposed out crops. The formation is composed mainly of siltstone (Sl-Fl) and shale (Fsc) facies. The Sl facies is fine to very fine grained, dark green to greenish brown, horizontally laminated siltstone. The interbedded siltstone to shale facies are believed to have been deposited in the lower most intertidal zone. The silts were deposited by high energy tidal current bed load traction whereas the shale represent suspended particles that settled out during slack water periods (Mazzullo, 1978). This facies are similar to characteristic of modern and ancient tidal flat deposits (Klein, 1967a and 1970b; Reineck, 1967). These interbedded rocks (decimeter scale) are not exactly analogous to them.

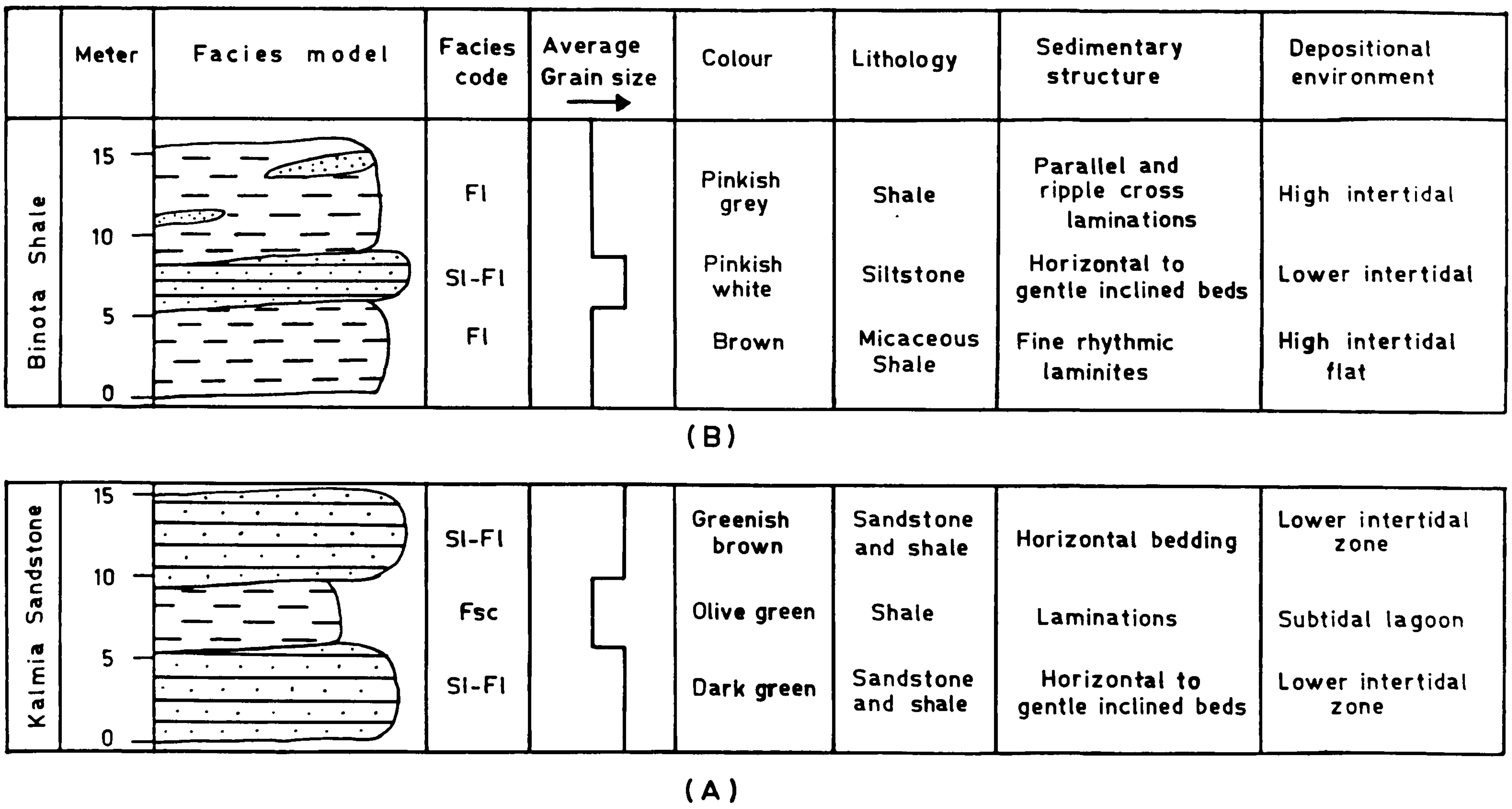


Fig. 41 Generalized Facies models of Kalmia Sandstone Formation (A) and Binota Shale Formation (B).

The Fsc facies comprises mainly calcareous shale with occasional lenses of siltstone. The shale are thin bedded (1mm to 1cm) to massive, splintery dark green to dark red. This green coloured shale which abounds in this facies may be due to persistent reducing conditions due to the high water table (Reading, 1978). The calcareous shale, the main constituent of this facies represent deposition from suspension in a low energy environment of subtidal lagoon as is evidenced by their parallel lamination and general absence of current and wave formed structures (Reinson, 1984; Walker, 1984).

BINOTA SHALE FORMATION

The formation is consists of thin to medium bedded (1 to 2cm) shales and silty shales (Fl) (Fig. 41 B). The lithologic and structural aspects of these rocks are similar to those of modern and ancient high tidal Flats (Klein, 1967 a, 1970 b; Reineck, 1967; Kuijpers, 1970; Mazzullo, 1978).

Fine Rhythmites : Upper (high) Intertidal

Sequence of finely interlaminated (mm scale) argillaceous siltstone and shale, with lenticular beds in siltstone, are characteristic of Fl facies. Such fine laminates are similar to the "tidal bedding" deposits observed on modern high intertidal flats, whose deposition results from rapidly flowing waters of high suspended shale content (Reineck, 1967; Mazzullo, 1978; Boothroyd, 1985). The coarser laminae in these sequence represent low energy traction deposits, whereas the shales are suspensates that settled out during slack water periods.

KHORI-MALAN SANDSTONE FORMATION

A generalised facies model of Khori-Malan Sandstone is shown in Figure 42 based on number of outcrops sections measured in the study area. The facies model consists of recurring fining upward as well as coarening upwards cycles in the middle to upper part averaging 10 to 20m in thickness. Each lithofacies in terms of its code, sedimentary characters viz. colour, grain size, sedimentary structures and environment interpretation is illustrated in the facies model (Fig. 42). The dominant facies recognised in the Khori-Malan Formation in the study area are as follows: -

Facies	**Environmental Interpretation**
St - Trough cross bedded sandstone	Zone of breaking wave or
Sp - Planar cross bedded sandstone	Nearshore surf zone
Sm - Massive sandstone	Intertidal
Sl-Fl - Inter bedded sandstone and shale	Intertidal
Cm - Conglomerate	Transgressive lag

The Khori-Malan Sandstone Formation differs from the two underlying sandstone formations (Khardeola and Sawa) in that it consists predominantly of fine to very fined sandstone which are textually and mineralogically mature. The Khori-Malan Sandstone is the only sandstone in the Lower

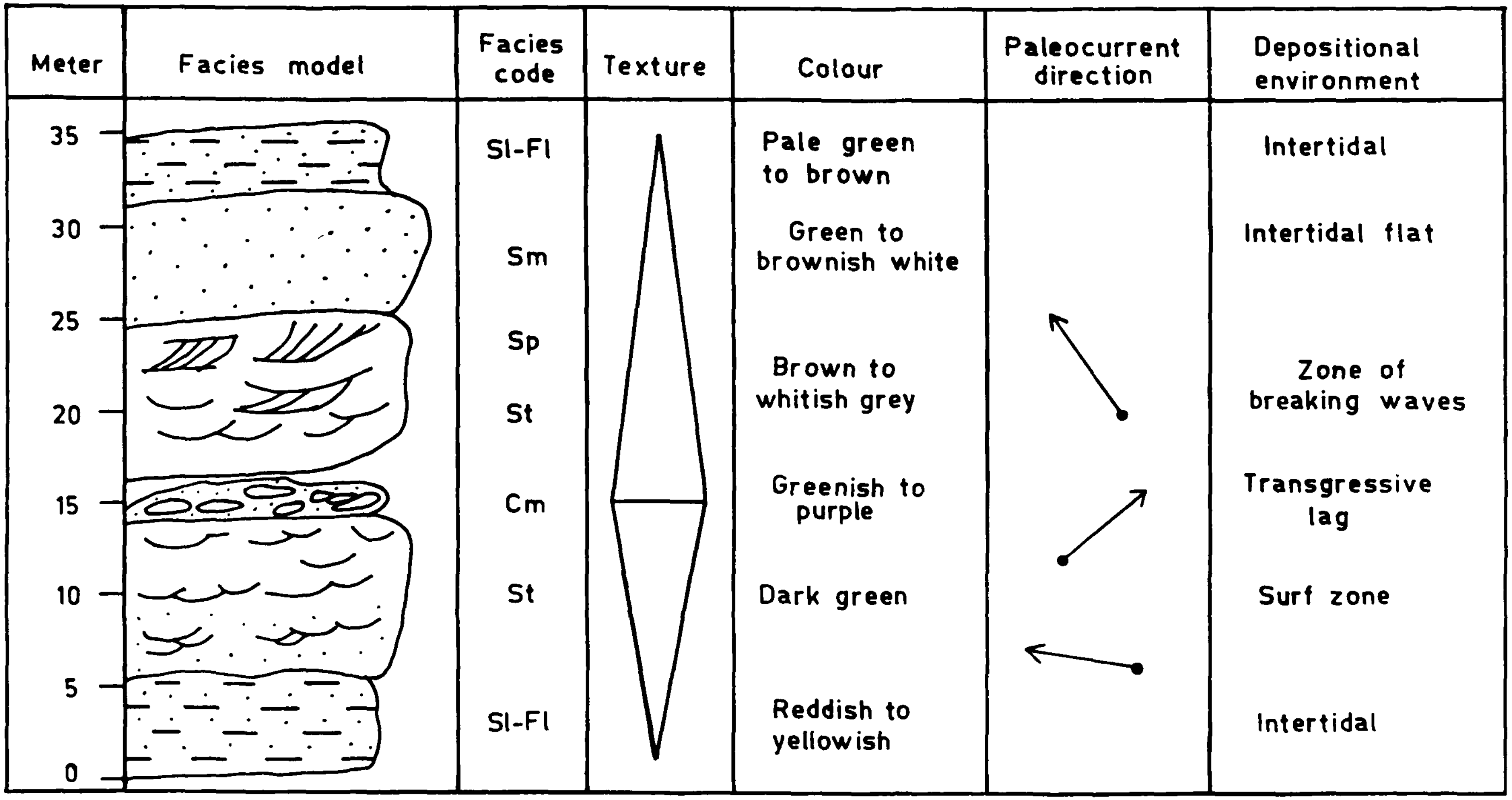


Fig. 42 Generalized Facies model of Khori-Malan Sandstone Formation. Facies code, texture, paleocurrent direction & probable depositional environments are listed alongside.

Vindhyan sequence that show mostly landward (north-west) dipping trough cross bed mostly of unimodal palaeocurrent model (Fig. 32).

The overall lithofacies association, grain size analysis and poorly coarsening or fining upward character of assemblage plus the dominant unimodal paleocurrents directed toward the landward in north-west of the study area and locally north and north-east clearly indicate a Barrier inlet to Nearshore surf environment with flood dominated tidal currents for Khori-Malan Sandstone Formation.

The major and minor depositional environments of Khori-Malan Formation are described here under and diagramatically picturised in Figure 42.

Trough and planar cross bedded sandstone (St and Sp) facies

The St or Sp facies comprises whitish pink and green, well sorted, fine to very fine grained sandstone underlying the cm facies. The presence of large scale trough and planar cross beds with inter beds of pebbles probably produced by the migration of linguoid and lunate megaripples (Clifton et al, 1971; Hunter et al, 1979; Davis, 1985; Decelles, 1987 and Einsele, 1992) indicates that St as Sp facies was deposited within the zone of breaking waves or surf zone of Nearshore (Einsele, 1992). The predominant distribution in this facies reflect a dominance of landward driven flood dominated tidal currents. Clifton et al, 1971 noted that the dominant current direction is landward (producing land ward dipping cross beds) in their outer rough or lunate megaripple zone on the nonbarred Oregon Coast. The studies of modern barred coasts by Davidson - Arnott and Green Wood (1976), Hunter et al (1979), Short (1984) and Green Wood and Mittler (1985) indicate that similar sedimentary structure are formed by land ward dominant flow on the seaward sides and crests of offshore bars.

Conglomerate (Cm) facies

Clusters of floating pebbles are isolated along horizons that are sandwiched by fine grained, cross bedded sandstone facies. These well sorted conglomerate lenses interpreted as a transgressive lag or ravinement (Swift, 1968; Decelles, 1987) produced by the winnoing action of surf zone waves during a transgressive episode.

Massive sandstone (Sm) and interbedded sandstone and shale (Sl-Fl) facies - Intertidal deposits

Massive sandstone (Sm) and interbedded sandstone and shale sequence represent intertidal environment of deposition (Klein, 1985). These association of facies consists of dark green to brown, moderately well sorted, silty to fine grained sandstone. The sandstone is generally horizontal or inclined bedded or massive, but locally contains horizontal lamination of silty material in the upper part interpreted that suspension processes of sediment transport occur over intertidal flats during periods of submergence (Mazzullo, 1978; Boothroyd, 1985).

JIRAN FORMATION

A generalised facies model of the succeeding Jiran Formation is shown in Figure 43 based on a number of outcrop sections in the study area. The facies model consists of coarsening and fining upward thinner cycles of about 5 to 10m thickness. Each lithofacies in terms of its code, sedimentary characters viz. colour, grain size, sedimentary structure and environmental interpretation as illustrated in the facies model (Fig. 43). The facies recognised in Jiran Formation in the study are as follows :

Facies	**Environmental Interpretation**
St - Trough cross bedded sandstone	ebb dominated tidal channel/delta
Sm - Massive sandstone	Middle shoreface
Sr - Rippled laminated sandstone	Tidal inlet/ intertidal zone
Sl - Fl - Interbedded sandstone and shale	Foreshore beach
S-hb - Herringbone cross bedded sandstone	Tidal currents
Fl - shale	subtidal lagoon/ intertidal zone

The overall lithofacies association, grain size analysis, dominant unimodal to bimodal paleocurrent directed towards Southeastern (seaward) and North-eastern build up that

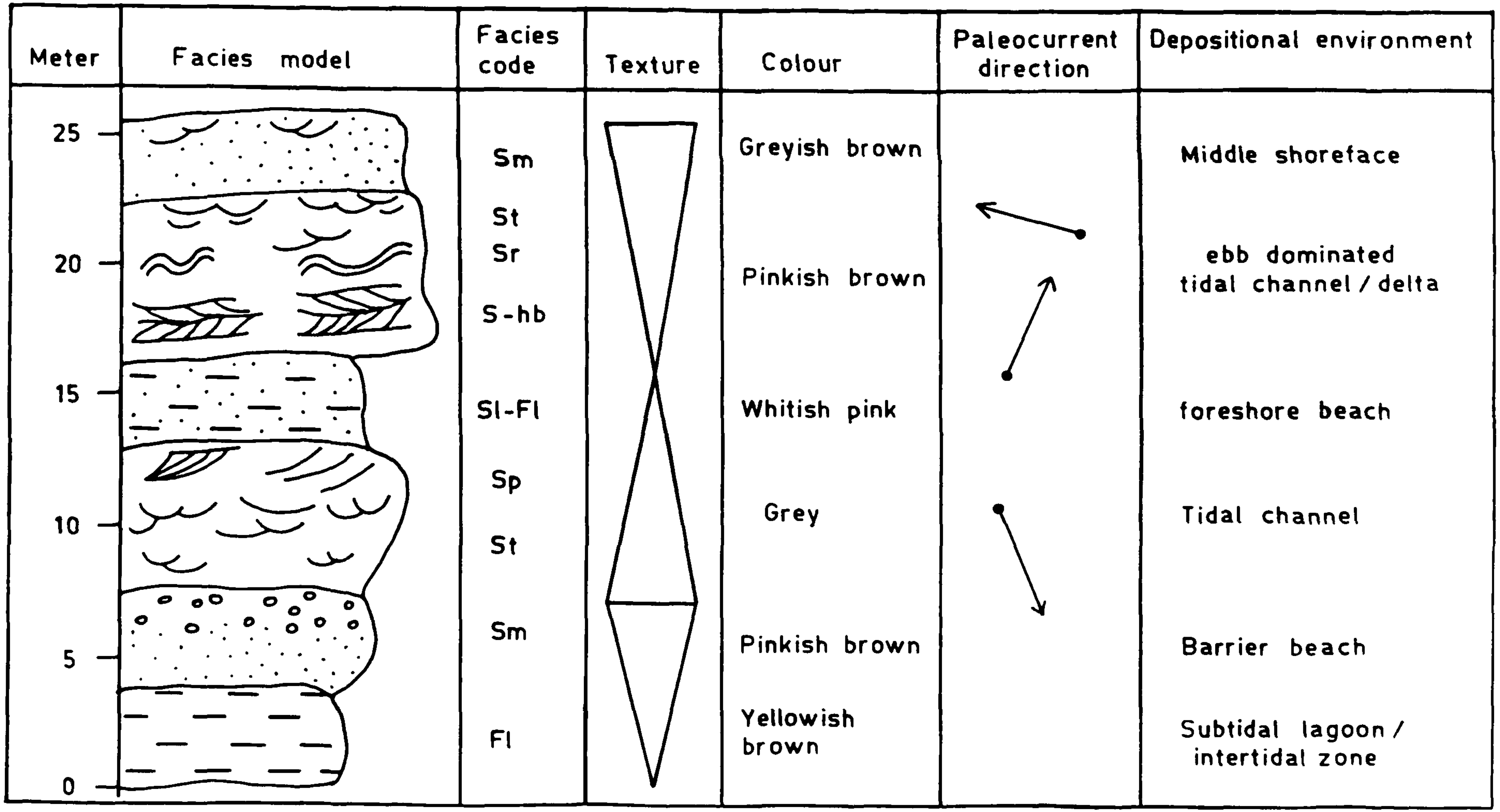


Fig. 43 Generalized Facies model is showing commonly occurring vertical transition of different facies in the Jiran Sandstone Eormation.

Jiran Formation represent a foreshore barrier beach, barrier inlet, ebb dominated tidal delta and intertidal in a regressive prograding nearshore environment.

The major and minor depositional environments of Jiran Formation described here under and diagramatically picturized in Figure 43.

Trough cross bedded sandstone (St) facies

The St facies consists of reddish brown to pinkish white, fine to veryfine grained, well sorted sandstone. Individual sandstone bodies of this type vary from 10cm to 1m in thickness. The St facies is comprises dominantly of unimodal to bimodal trough bed paleocurrent but locally trimodal and quadrimodal (Fig. 33 & 34) at places is also recorded.

The St facies characterised by local fining upward texturally, a thinning upward of cross bed set thickness, bidirectional trough cross bed and an erosional base marked by a coarse lag deposit (Sm). This St facies may probably produced by migration of barrier inlet or tidal channel (Land, 1972; Kumar and Sanders, 1974; Hubbard and Barwis, 1976; Barwis and Makurath, 1978; Carter, 1978; Hayes, 1980 and Reinson, 1984 and Enisele, 1992). But this facies show dominantly unimodal seaward (South-easterly) oriented trough cross beds which probably formed by ebb dominated tidal currents (Klien, 1985; Einsele, 1992). For this reason the St facies show mostly abundance of unimodal distribution of trough cross beds, low variance and scarcity of herringbone pattern (Klein, 1970 a, P. 1118).

Massive sandstone (Sm) facies

The Sm facies overlies the Fl and St facies in the lower and upper part of the Jiran sequence respectively. The Sm facies comprises pinkish white to tan, very fine to fine grained, well sorted sandstone. The sandstone is generally massive, but locally contains horizontal or trough cross beds. This facies show upward coarsening textural distribution which reflect the regressive or Nearshore progradational sequence (Hunter et al, 1979). This facies may suggest deposition in middle shoreface environment (Galloway and Hobday, 1983, P. 123; Reinson, 1984) or in shallow water (Willis et al, 1972) or else by erosion of the underlying bars under upper flow regime (Harms & Fahnestock, 1965). The fine to very fine grained, thick bedded (Sm) facies in the upper part may suggest deposition in quite water condition during retreat of sea water condition. The local trough cross beds probably were formed by small run off channels on the upper beach (Decelles, 1987).

Interbedded sandstone and shale (Sl-Fl) facies

The middle part of Jiran sequence is characterized by pinkish white, fine to very fine grained, well sorted sandstone (Sl) with thin interbeds of siltstone (Fl). The Sl-Fl facies is overlain and underlain by St facies along a sharp, roughly horizontal contact. The predominant sedimentary structure in this facies is sub parallel, horizontal, thin bedded, gently dipping seaward (south-east) beds. This facies indicate probably beach foreshore deposit (Decelles, 1987; Galloway & Hobday, 1983).

Rippled laminated sandstone (Sr)

This facies (Sr) develops in the upper part of the fine to very fine grained, well sorted, massive and cross bedded (St or Sp) Jiran Sandstone, exhibiting ripple marks on the bedding planes. The Sr facies occur as long crested, wave generated symmetrical and current ripples on the bedding planes of massive and cross bedded sandstone. The long crested symmetrical ripples have a wave lengths of 3 to 5cm, an amplitude of 2 to 5mm and north-south orientation. On the some bedding planes long crested current ripples are common with wave lengths of 2 to 7cm and amplitude 2 to 4mm.

This facies with association of cross bedded facies appears to have been deposited in tide dominated environments. The sandstones of this facies may be deposited in both a shallow subtidal and intertidal low tidal flat or low tidal sand bar environment (Klein, 1970 a; Mackenie, 1975; Mazzullo, 1978; Hubbard and Barwis, 1976; Hayes, 1980). The asymmetric current ripples suggest tractional tidal current under the lower flow regime (Klein, 1970 b, Knight et al, 1975). These linear ripples may also formed by flood or ebb tidal currents on the intertidal portion of flood or ebb tidal delta (Boothroyd, 1985; Einsele, 1992).

Shale (Fl) facies

The Fl facies comprises mainly shale with occasional interbeds of siltstone. The shale are thin bedded (1mm to 1cm), laminated, splintery dark brown to pinkish yellow. The Fl facies are believed to have been deposited in the lower most intertidal zone (Mazzullo, 1978; Boothroyd, 1985). The silt bed were laminated and deposited by high energy tidal current bed load traction where as the shale represent suspended particle that settled out during quite water periods (Klein, 1985).

Herringbone cross bedding (S-hb) facies

The upper part of Jiran sequence is characterized by reddish brown to pinkish white, fine to very fine grained, poorly herringbone cross bedded sandstone. Individual sandstone bodies of this type vary from 1 to 2m in thickness. Thin bedded siltstone is generally present between two sandstone bodies in a vertical sequence. Some evidence of herringbone cross bedding is generally recorded in the upper part near Bari and Bamaniya area and interpreted as reversal (bipolar-bimodal pattern) tidal currents (Klein, 1971, 1985, P. 193; Reading, 1978; Mazzullo, 1978, P. 235; LeeKie & Walker, 1982;Reinson, 1984, P. 127; Boothroyd, 1985, P. 472; Einsele, 1992). Cross bedding direction in this facies are opposed variably (e.g. $311^{\circ} \pm 41^{\circ}$ and $118^{\circ} \pm 43^{\circ}$; $11^{\circ} \pm 23^{\circ}$ and $191^{\circ} \pm 26^{\circ}$) indicating that during the deposition of this facies, seaward (south-east) and landward (north-west) directed tidal currents (ebb and flood currents) were active in producing the bidirectional cross bedding. Reading (1978, P.235) attributed the herringbone type of sedimentary structures in sandstone bodies as a diagonstic feature of tidal currents. Clifton and Thompson (1978) attributed these structures to intertidal and shallow subtidal environments. Boothroyd (1985, P. 472) described that herringbone cross bedding is excellent indicator of reversing or bidirectional flow in estuaries environment.

BARI FORMATION

A generalised facies model of the Bari Formation of Khorip group is shown in Figure 44(A) based on a number of exposed outcrops. Each lithofacies in terms of its code, sedimentary character viz; colour, grain size, sedimentary structure and environmental interpretation is illustrated in the facies model (Fig. 44 A). The facies recognised in the Bari Formation are as follows :

Facies	**Environmental Interpretation**
Fsc - calcareous shale	Subtidal lagoon to high tidal flat
Fl - Laminated siltstone to shale	intertidal zone

The most common lithologies in the lower part of Bari Formation are laminated siltstone to shale (Fl) facies and in middle and upper part calcareous shale (Fsc) facies.

Calcareous shale (Fsc) facies

The Fsc facies comprise mainly calcareous shale with occasional lenses of flat pebble siltstone. The shale are thin bedded (1mm to 1cm) to massive, splintery, dark green to dark pinkish red. The green coloured shale which abounds in this facies may be due to persistent reducing conditions due to the high water table (Reading, 1978). The calcareous shale, the main constituent of this facies represent deposition from suspension in a low energy environment of subtidal lagoon as is evidenced by their parallel lamination and general absence of current and wave formed structures (Reinson, 1984). However, the presence of mud cracks and flat pebbles at certain levels in the sequence is suggestive of intertidal conditions. Therefore, the lithologic and structural aspects of these are similar to those of modern and ancient high tidal flats (Klein, 1967 a, 1970 b; Reineck, 1967; Kuijpers, 1970; Mazzullo, 1978; Boothroyd, 1985). The finely interlaminated (mm scale)argillaceous shale and siltstone with lenticular beds in the later, are characteristic of this facies. Such fine laminites are analogous to the "tidal bedding" deposits observed on modern high intertidal flats, whose deposition results from rapidly flowing waters of high suspended mud content (Reineck, 1967). The coarser laminae in these couplets represent low energy traction deposits, where as the shales are suspensates that settled out during slack water periods.

Laminated siltstone to shale (Fl) facies

The Fl facies comprise pale pink laminated siltstone to shale. The siltstone is fine laminated and micaceous. The Fl facies are believed to have been deposited in the lower most intertidal zone : the silts were laminated and transported by

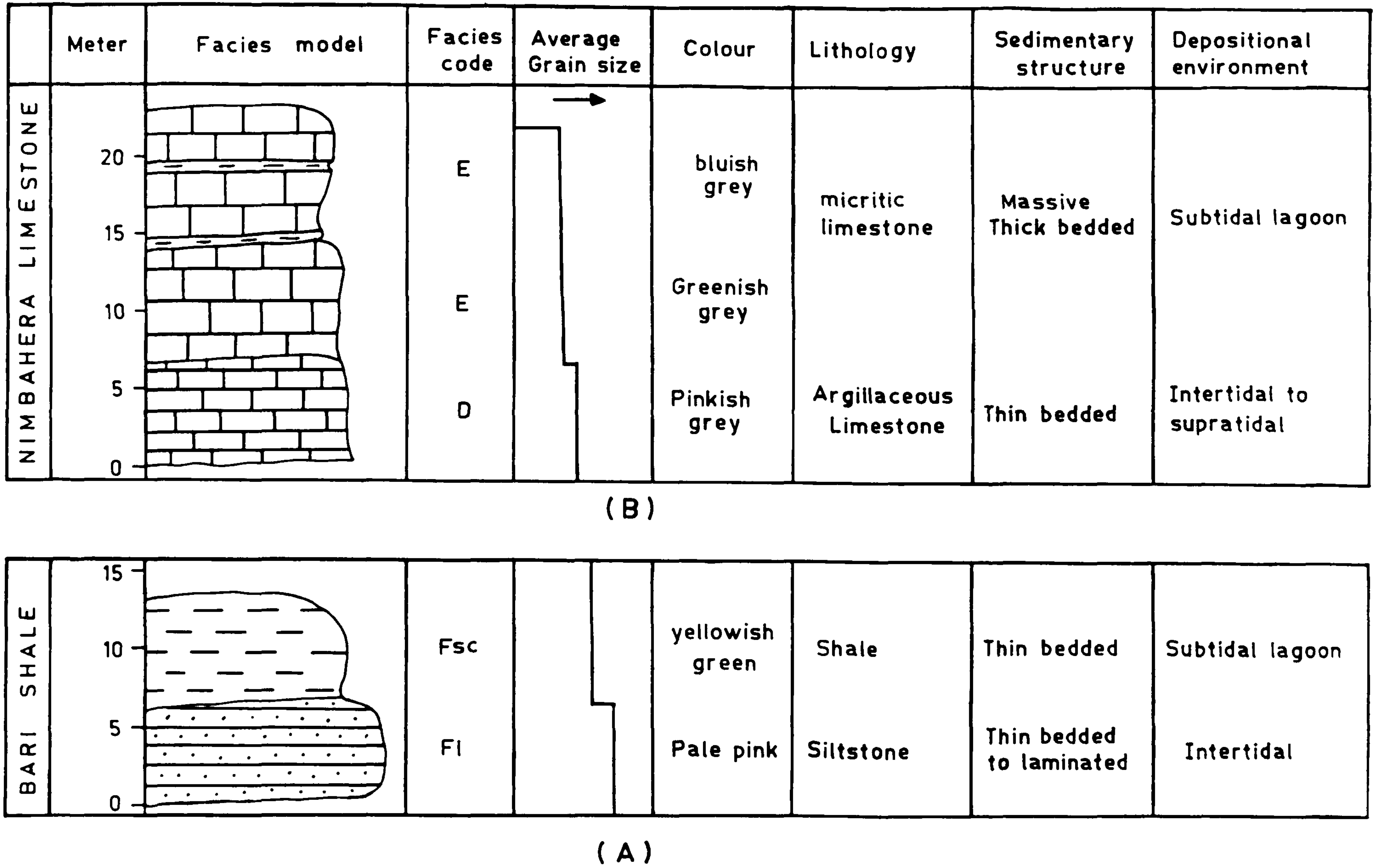


Fig.44 Generalized Facies models of Bari Shale Formation (A) and Nimbahera Limestone Formation (B)

high energy (lower upper flow regime) tidal current bed load traction where as the shale represent suspended particles that settled out during quite water periods (Mazzullo, 1978). Although coarse rhythmically laminated beds (mm-cm scale) are characteristic of modern and ancient tidal flat deposits (Klein, 1967 a & 1970 b; Reineck, 1967). These siltstone (decimeter scale) are not exactly analogous to them.

The overall lithofacies association and petrographic character of the assemblage represent that Bari Formation may be formed in intertidal to subtidal lagoon environment.

NIMBAHERA FORMATION

A generalised facies model of the Nimbahera Formation of Khorip group is shown in Figure 44(B) based on a number of outcrop sections. Each lithofacies in terms of its code, sedimentary character viz. colour, grain size, sedimentary structures and environmental interpretation is illustrated in the facies model (Fig. 44 B). The dominant facies recognised in the Nimbahera Formation are as follows :

Facies	**Environmental Interpretation**
Lithofacies D	Upper intertidal to supratidal flats
Lithofacies E	Subtidal lagoon

The most common lithologies in the lower part of Nimbahera limestone are lithofacies D and in middle and upper part lithofacies E.

Lithofacies D - Intertidal to supratidal deposits

The main constituent of this lithofacies is pinkish grey, thin bedded argillaceous micritic limestone (silty micrite). This facies under microscope shows Bird's eye or fenestrae structure and contains appreciable amount of terrigeneous admixture such as detrital quartz, chert and quartzite. Bird's eye or fenestrae structures are reported to be highly characteristic of supratidal sediments (Shinn, 1968; Shinn et al, 1969, P. 1210) or upper intertidal to supratidal environments (Shinn, 1983). The abundance of fenestrae structure, terrigenous admixture and argillaceous micritic composition of this lithofacies may interprete to represent upper intertidal to supratidal flats environments.

Lithofacies E - subtidal lagoon deposits

The most common lithologies in this facies is pale bluish grey to dark grey colour, thick bedded, massive limestone. This lithofacies is almost entirely composed of micrite and neomorphosed micrite and the abundance of micrite suggests a low energy subtidal environment of deposition where the current action was not enough to winnow out the micrite (Folk, 1980). Micrite is mainly formed in shallow sheltered lagoonal areas or on broad, submerged shelves of little relief and moderate depth where wave action is cut off by the very width of the shelf (Blatt et al, 1972; Minero, 1991). Terrigeneous admixture and high energy structure such as ripple marks, intraformational breccia, stromatolite and scour and fill are completely absent from this lithofacies and the other features suggestive of wave and current action and intermittent exposure are rare. Lithofacies E is interpreted as a deposit of a shallow subtidal lagoon on the basis of evidence such as abundance of micrite, general absence of feature suggestive of intermittent exposures and blackish grey colour of limestone.

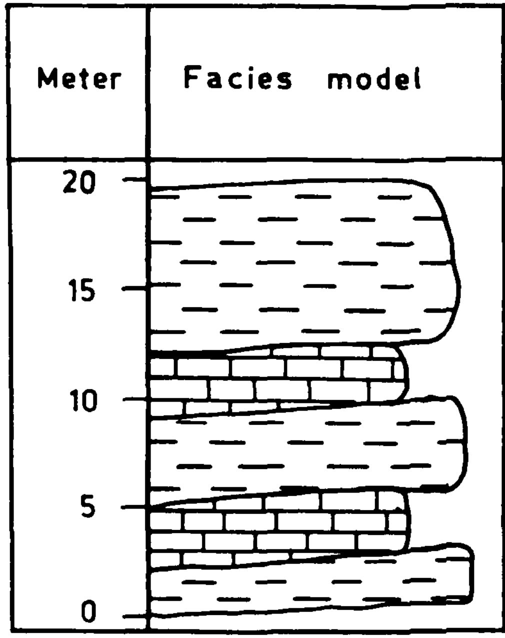
The overall lithofacies association and petrographic character of the assemblage represent that Nimbahera Limestone may be formed in subtidal lagoon to intertidal flats.

SUKET FORMATION

A generalised facies model of Suket Formation of Khorip group is shown in Figure 45 based on a exposed outcrops. The formation is mainly composed of calcareous shale (Fsc) with inter beds of argillaceous micritic limestone (lithofacies-D) in the lower part.

The Fsc facies comprises mainly calcareous shale with occasional lenses of siltstone. The shale are thin bedded (1mm to 1cm) to massive, splintery, pale greenish to chocolate brown. The calcareous shale, the main constituent of this facies represent deposition from suspension in a low energy environment of subtidal lagoon as is evidenced by their parallel lamination and general absence of current and wave formed structures (Reinson, 1984).

The interbeds of argillaceous micritic limestone (lithofacies - D) occur in the lower part of Suket Formation. The microfacies of this facies shows Bird's eye or fenestrae structure which is characteristic of upper intertidal to supratidal environments (Shinn, 1983).



Facies code	Colour	Lithology	Sedimentary structure	Depositional environment
Fsc	Chocolate brown	Shale	Thin bedded	Subtidal lagoon
D	Bluish grey	Micritic limestone	Laminations	Upper intertidal
Fsc	Reddish brown	Shale	Thin bedded	Subtidal lagoon
D	Bluish grey	Micritic limestone	Laminations	Supratidal
Fsc	Dark red	Shale	Thin bedded	Subtidal lagoon

Fig. 45 Generalized Facies model of Suket Shale Formation.

The overall lithofacies association and petrographic character of the assemblage represent that Suket Shale Formation may be formed in subtidal lagoon to intertidal zone.

PALEOGEOGRAPHY AND BASIN TECTONICS

Integrated study of lithofacies framework and depositional environments helps in reconstructing the paleogeographic scenario and mode of sedimentation for the Lower Vindhyans in the South-eastern Rajasthan.

The Vindhyan rock were deposited on the peneplained upper Archaean (2500 - 3200 m.y.) and lower Proterozoic (1900 $\pm$ 100 m.y. - 2500m.y.) basement rocks having irregular topography. At that time, irregularities of the basin floor were present in the form of buried ridges and sub basins. The Vindhyan basin was related to the northern epicontinantal sea with an opening on east during Lower Vindhyan and its connection was establish through a constricted channel with the western part encircling the Bundelkhand massif (Ahmed, 1971). Thus the paleogeographic setting as it appears that northern sea formed the intracratonic Vindhyan basin bounded by the Great Boundary Fault in the north west and Narmada - Son Fracture in the south east. The general shape suggested by this setting is a U shape, the axis of which extending NE-SW direction. Taking as a whole, the Vindhyan basin was that of an intracratonic Yoked basin, a type of residual geosyncline of Peyve and Sintzyn (1960) as quoted in Aubouin (1965).

The bulk of the cross bedded sandstone bodies and fine clastics including shale of the Khardeola Formation may represent deposition in shoreface to foreshore of coastal environments. The foreshore and backshore currents flowed dominantly reverse NW and SE direction as brought out by cross bedding foreset orientation. Back barrier or subtidal lagoon areas providing suitable environments for the accumulation of fine clastics and shale. The coarsening upward character occasionally noted in Khardeola Sediments may like wise be attributed to prograding shoreface to foreshore environments. The succeeding Bhagwanpura Limestone Formation is characterised by stromatolite, intraformational breccia, shale, sandstone was deposited largely in low energy subtidal lagoon and tidal flat environments.

The Sand group is characterised by coarsening and fining upward cycles of cross bedded sandstone in the lower (Sawa Sandstone) formation and laminated Palri shale (upper formation). The Sawa Sandstone is represent oblique-bar-rip channel nearshore system where sediments were deposited by longshore, rip and tidal currents as is evident by trimodal palaeocurrent flow distribution of cross beds. The Palri shale of the Sand group may represent deposition in intertidal environment.

The argillaceous Lasravan group again show intertidal environment of deposition. However, most of the sandstone bodies of the succeeding Khorip group with large cross bedding directed mostly southeast or northeast and northwest, possibly were formed by flood or ebb dominated tidal currents, longshore and rip currents. The associated fine clastics (Bari and Suket shale) and carbonate (Nimbahera Limestone) rocks may suggest subtidal lagoon through upper intertidal to supratidal flat environments.

In summing up, the development of Middle Proterozoic Vindhyan basin of southeastern Rajasthan is a tectonically significant event, might have originated as a result of reactivation of fundamental tectonic lineaments during rejuvenation of the Aravalli range towards the close of the Delhi sedimentation. Consequently the Vindhyan basin is initiated sedimentation with volcanic activity. The volcanic activity is indicative of deep seated fracture along the western margin of the vindhyan basin which resulted due to the reactivation of the fundamental lineaments at the start of the Vindhyan sedimentation. Thus through out the Vindhyan sedimentation, the condition of deposition were fluctuating due to subsidence and the elevation of the area of deposition and consequent transgressions and regressions. Thus the sedimentation in the given basin was brought about by coastal currents including longshore, rip channel and tidal currents on a fluctuating marine condition in a shallow intracratonic basin. As sedimentation progressed from Satola, Sand through Lasravan to Khorip group, the depositional environment remained mainly nearshore to tidal flat.

CHAPTER - VII

SUMMARY AND CONCLUSIONS

The Middle Proterozoic Vindhyan rocks occur in Bhadesar-Nimbahera area of southeastern Rajasthan. The Lower Vindhyan rocks of the study area representing about 1171m thick clastic sequence comprising sandstone, shale and limestone and cover an area of about 675 sq.km. The present study deals with stratigraphy, lithofacies, paleoflow analysis, textural and mineralogical composition of the Middle Proterozoic rocks and aims to determine paleoflow and paleoslope, provenance, depositional history and paleogeography of the sediments in the given area.

The main conclusions of this study are summarised here under : -

1. The study area was geologically remapped on a scale of 1:50,000 and four group were recognised and delineated. The four group in the ascending order are Satola (474m), Sand (140m), Lasrawan (175m) and Khorip (382m). The sequence in each group mostly comprises sandstone, shale and limestone and show recurring assemblage of fining or coarsening upward cycles.

   The Satola group abound in calcareous including fine clastic with subordinate amount of coarse sandstone. The succeeding Sand group show a progressive increase of coarse clastics and higher up in sequence the Lasrawan group again argillaceous and the Khorip is the youngest group of Lower Vindhyan rocks which is mainly calcareous and arenaceous. Thus the repetitive sequence of sandstone, shale and limestone is a clue to fluctuating basin condition.

2. Sixteen lithofacies were recognised in the Lower Vindhyan rocks on the basis of lithology, grain size and sedimentary structures. These lithofacies are : Trough cross bedded sandstone (St); Planar cross bedded sandstone (Sp); Massive sandstone (Sm); Massive conglomerate (Cm); Interbedded sandstone and shale (Sl-Fl); Horizontal bedded to laminated sandstones (Sh); Laminated siltstone to shale (Fl); Calcareous shale (Fsc); Channel sandstone (Sch); Ripple laminated sandstone (Sr); Herringbone cross bedded sandstone (S-hb); Lithofacies A; Lithofacies B; Lithofacies C; Lithofacies D and Lithofacies E.
St and Sp facies representing predominantly fined to medium grained, pink, grey sandstone and show extensive development of large and medium scale coset. Cm facies developed locally includes small pebbles (2-4mm), earthy yellow to greyish white in colour, which are commonly subangular to subrounded and predominantly quartzose in composition. Sr and Sh-b facies developed locally in fine to very fine grained, pinkish white and red sandstone. Fl and Fsc facies representing shale and very fine grained sandstone. Lithofacies A to E representing limestone facies and show several

structure such as laminated bed, stromatolite, intraformational breccia, ripple marks and desiccation cracks.

3. Paleoflow study of the Lower Vindhyan rocks was undertaken to examine paleocurrent in each major sandstone formation and its implication in basin analysis and configuraction. The study is based on 1310 readings of cross bedding foreset dip azimuth of Khardeola (144), Sawa (463), Khori-Malan (325) and Jiran (378) sandstones. The data were analysed at locality, sector and formation-level. The study reveals inconsistency in the paleoflow pattern and a paleoslope from NW-W to SE-E during the course of sedimentation from Khardeola at the base through Sawa (excluding Khori-Malan sandstone) to Jiran Formations at the top. However, during the deposition of Khori-Malan Sandstone Formation, the paleoslope was in reverse direction i.e. SE to NW as indicated by paleocurrent flow pattern.

4. The textural analysis of sandstones indicates that mean grain size increases from Khardeola (1.42 - 3.39 ϕ) through Bhagwanpura (1.92 - 2.38 ϕ) to Sawa (0.85 - 2.23 ϕ) and decreases through Khori-Malan (1.02 - 3.62 ϕ) to Jiran (1.78 - 3.9ϕ). Similarly the bulk of the sandstone demonstrate positive (+) to negative (-) skewness. By and large the sandstone is moderately to well sorted and subrounded.

5. Petrographically four types of sandstone characterise the Lower Vindhyan rocks, mainly Quartz arenite, subarkose, sublitharenite and Arkose as listed below :-

	Quartz-arenite	Subarkose	Sublith-arenite	Arkose
Khardeola	54.54%	27.27%	18.18%	-
Bhagwanpura	-	50%	50%	-
Sawa	37.5%	43.75%	6.25%	12.5%
Khori-Malan	44.44	-	55.55	-
Jiran	80%	10%	10%	-

Quartz as the most dominant constituent, include monocrystalline variety of igneous and sedimentary and polycrystalline variety of metamorphic origin. Feldspar is next to quartz and includes mainly microcline and orthoclase and locally plagioclase. The rock fragments consist of quartzite, chert, quartz schist, silt and shale. Four type of cementing material (Silica, chert, iron oxide, carbonates) and three types of detrital matrix (ortho, pseudo, epi matrix) occupy the pore spaces of the framework constituents in varying proportion. Heavy minerals are represented by zircon, tourmaline and opaques.

6. Petrographically limestone is composed of four main constituents namely : intraclast, sparry calcite cement, micrite and dolomite. Four microfacies were

recognized in the limestone rock, namely micrite, silty micrite, Intramicrite and dolomitized micrite. Terrigeneous admixture such as detrital quartz, quartzite, chert, calcite grains are present mostly in limestone rocks.

7. Quartzose pebbles in conglomeratic sandstone and overall composition of framework constituents and heavy minerals provide evidence of mixed composition for the provenance, comprising acid igneous (granite and pegmatite), low to medium grade metamorphic rocks (gneiss and slate) and pre-existing metasedimentary (Quartzite) and sedimentary rocks. Indeed rocks of similar composition constitute the Bhilwara super group, Berach Granite and Bhadesar Quartzite well exposed in the north through west to southern part of the study area. The south easterly, east and north easterly directed paleocurrent corroborate the above contention and locates the provenance in west, northwest and south. The study reveals, beyond doubt, that the given Lower Vindhyan rocks were derived largely from the Bhilwara Supergroup, Berach Granite and Bhadesar Quartzite high lands situated around the study area (excluding the eastern side).

8. Generalised facies model provide a basis for reconstructing the broad depositional environment of each formation of the Lower Vindhyan rocks as follows :

The Khardeola Formation is consisting dominantly sandstone with thinly bedded shale and occasionally display a coarsening upward sequence. The planar and trough cross bedding foresets commonly exhibit polymodal distribution with mean direction towards southeast ($125^{\circ} \pm 76^{\circ}$) and secondary direction toward north west. It is suggested that Khardeola sedimentation was brought about by south easterly coastal current with coarsening upward character may represent shoreface to foreshore environments with occasional influence of north westerly floodtidal and/or Backshore currents.

The Bhagwanpura Formation is composed of mainly stromatolitic micritic limestone with subordinate amount of shale and sandstone. The formation is characterised by stromatolites, ripple marks, intraformational breccia, desiccation cracks, Bird's eye or fenestrae structure with terrigeneous material. The overall lithofacies association and petrographic character of the assemblage represent that Bhagwanpura Limestone Formation may be formed in a protected low energy subtidal lagoon to tidal flat environment.

The Sawa Formation is composed mainly of coarse to medium grained sandstone with occasional inter beds of conglomerate and characterised by coarsening and fining upward cycles. The planar and trough cross bedding foresets commonly exhibit polymodal distribution with main mode directed toward southeast and secondary mode towards northwest and north east directions. The overall lithofacies association, coarsening/ fining upward sequences, grain size analysis and the dominant bimodal paleocurrent distribution indicate that Sawa sequence may represent a oblique bar-rip channel nearshore environment with the intermittent tidal influence in the middle part of the sequence.

The Palri Formation is mainly whitish grey to pale green shale with very fine grained thin porcellanite bed. This formation may be deposited into subtidal lagoon (Back-Barrier) environment.

The Kalmia Formation is mainly composed of siltstone and shale and may be deposited into lower intertidal zone to subtidal lagoon environment. The Binota Formation is again consists of thin to medium bedded shale and silty shale. The lithologic and structural aspects of these rocks are similar to those of high tidal flats.

The Khori-Malan Formation is consist predominantly of fine to very fine grained sandstone with interbeds of congolomerate in the upper part of the sequence. The cross bedding foresets commonly exhibits unimodal distribution with mean orientation towards northwest ($341^{\circ} \pm 70^{\circ}$). It is suggested that Khori-Malan Sandstone may be deposited into Barrier inlet to nearshore surfzone with influence of flood dominated tidal currents.

The Jiran Formation is characterised by fine grained, trough cross bedded, pinkish brown sandstone. The overall lithofacies association, grain size analysis, polymodal paleocurrent distribution indicate that Jiran Sandstone may be deposited into foreshore barrier beach to ebb dominanted tidal delta in a regressive prograding nearshore environment.

The Bari Formation is represented by calcareous shale and siltstone rock and may be deposited into subtidal lagoon to intertidal zone environment. The Nimbahera Limestone Formation is composed of thin bedded argillaceous micritic (lithofacies D) and thick bedded micritic limestone (lithofacies E) and may be deposited into subtidal lagoon to tidal flats environments. The Suket Formation is mainly composed of calcareous shale with interbeds of argillaceous micritic limestone in the lower part and may be deposited into subtidal lagoon to intertidal zone.

9. The bulk of the detrital of the Lower Vindhyan rocks of the study area, includes quartz, feldspar, rock fragments and heavy minerals may have their derivation largely from Bhilwara supergroup, Berach Granite, Bhadesar quartzite and phyllite rocks. Admittedly, these rocks at the present time are widely exposed in north, west and south of the study area as corroborated by the paleocurrent study.

10. The Middle Proterozoic Vindhyan basin lying in study area in southeastern Rajasthan provides good example of shallow intracratonic sub-basin developed on the western margin of the Vindhyan basin. The sedimentation in this part of the basin was brought about for the first time under oscillating basin condition by coastal currents including longshore, rip-channel and tidal currents. The depositional environments remained mainly shallow marine, nearshore-barrier beach to tidal flat through out the Lower Vindhyan sedimentation.

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Appendix - I Grain Size frequency distribution (Number percent) of Lower Vindhyan Sandstones of Bhadesar - Nimbahera area, Southeastern Rajasthan. (Data based on thin section analysis)

S. No.	Sample Number	Grain Diameter in phi (ϕ) units													
		-2.0 to -1.5	-1.5 to -1.0	-1.0 to -0.5	-0.5 to 0.0	0.0 to 0.5	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5to 5.0
						KHARDEOLA SANDSTONE									
1	66	-	-	-	-	5	10	30	23	14	17	1	-	-	-
2	3'	-	-	-	-	-	1	10	47	28	11	2	1	-	-
3	5'	-	-	-	-	6	26	53	14	1	-	-	-	-	-
4	69	-	-	-	-	1	9	38	36	11	5	-	-	-	-
5	70	-	-	-	-	-	1.63	20.41	40.82	24.49	11.02	1.63	-	-	-
6	71	-	-	-	-	-	1.22	4.9	23.27	36.33	31.43	1.22	1.63	-	-
7	59'	-	-	-	-	5	15	23	21	10	10	9	6	1	-
8	45'	-	-	-	-	-	1	5	13	40	36	3	2	-	-
9	46'	-	-	-	-	-	-	1.33	45.33	42.66	8.0	2.66	-	-	-
10	62	-	-	-	-	-	-	-	-	1	23	47	27	2	-
11	42'B	-	-	-	-	2	10	52	29	6	1	-	-	-	-
12	3	0.41	1.24	1.65	1.65	5.37	9.09	23.55	17.76	19.83	14.46	4.54	0.41	-	-
						BHAGWANPURA SANDSTONE									
13	100	-	-	-	-	-	8	34	22	26	7	3	-	-	-
14	104	-	-	-	-	-	-	6	26	43	20	3	2	-	-
						SAWA SANDSTONE									
15	60'	-	-	-	-	8.33	14.58	25.42	15.42	15.0	15.42	5.0	0.83	-	-
16	61'	-	1.5	5.5	7.0	12	11.0	12.0	14.5	26.5	9.5	0.5	-	-	-
17	12'	-	-	-	-	5	19.0	36.0	15.0	11.0	14	-	-	-	-
18	14'	-	-	5	8	6	7	23	22	22	7	-	-	-	-
19	15'	-	-	2	2	12	10	22	23	18	9	1	1	-	-
20	81	0.9	0.9	1.36	0.9	2.27	6.81	20.45	20.45	22.27	17.27	3.63	2.27	0.45	-

S. No.	Sample Number	Grain Diameter in phi (ϕ) units -2.0 to -1.5	-1.5 to -1.0	-1.0 to -0.5	-0.5 to 0.0	0.0 to 0.5	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5 5.0
21	82	-	-	-	-	0.85	3.40	11.06	30.21	35.32	15.74	2.97	0.42	-	-
22	7'	-	-	-	-	3	18	43	21	13	2	-	-	-	-
23	9'	-	-	12	17	25	11	20	2	4	5	3	1	-	-
24	75	-	1	2	1	7	7	14	22	30	14	2	-	-	-
25	94	-	-	1	-	6	16	25	33	14	5	-	-	-	-
26	95	-	-	2	3	19	12	15	14	25	7	3	-	-	-
27	123	-	-	2.66	5.33	22.66	25.33	32.0	8.0	4.0	-	-	-	-	-
28	47'	-	-	1	8	17	15	21	18	10	10	-	-	-	-
29	48'	-	-	-	-	13	22	26	17	12	10	-	-	-	-
30	59	-	-	-	-	1	23	41	24	5	6	-	-	-	-
31	8	-	-	1.0	-	9.0	14.0	33.0	26	16	1	-	-	-	-
32	13	-	-	-	-	-	0.85	21.28	40.42	26.38	10.21	0.85	-	-	-
33	14	-	-	1.18	5.1	4.7	3.53	4.7	15.69	43.14	20.39	1.57	-	-	-
						KHORI - MALAN SANDSTONE									
34	4	-	-	-	-	-	1	1	4	46	36	8	4	-	-
35	32'	-	-	-	-	-	-	-	1.5	13.0	41.0	21.0	21.0	2.5	-
36	33'	-	0.78	2.35	1.57	5.88	10.58	24.70	17.64	14.90	13.33	6.27	1.96	-	-
37	34'	-	-	-	-	-	-	-	-	0.41	9.09	31.40	43.80	9.09	6.20
38	39	-	-	2	5	29	35	21	1	1	4	2	-	-	-
39	40	-	-	-	-	-	1.0	1.0	-	1.0	50.0	34.0	13.0	-	-
40	45	-	-	-	-	-	-	-	1	6	40	31	21	1	-

S. No.	Sample Number	Grain Diameter in phi (ϕ) units													
		-2.0 to -1.5	-1.5 to -1.0	-1.0 to -0.5	-0.5 to 0.0	0.0 to 0.5	0.5 to 1.0	1.0 to 1.5	1.5 to 2.0	2.0 to 2.5	2.5 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0 to 4.5	4.5 to 5.0
41	53'A	-	-	-	1.11	1.11	1.11	5.55	3.33	3.33	35.55	25.55	22.22	1.11	-
42	49	-	-	-	-	-	7.2	16.8	22.4	32.8	18.8	1.6	0.4	-	-
43	52	-	-	-	-	-	-	-	-	1.21	20.56	33.46	39.11	3.22	2.41
44	46A	-	-	-	-	-	-	-	-	1.0	23.0	29.0	40.0	6.0	1.0
						JIRAN SANDSTONE									
45	9B	-	-	2	3.3	4.0	2.0	4.0	2.66	14.0	38.0	18.66	10.66	0.66	-
46	10	-	-	-	-	3	3	5	1	16	58	12	1	-	-
47	11	-	-	-	-	-	-	-	-	24	68	8	-	-	-
48	25'	-	-	-	-	-	1	2	6	15	54	13	8	1	-
49	27'	-	-	-	-	-	-	-	-	1	23	51	24	-	-
50	26'	-	-	-	1	4	10	34	30	17	3	1	-	-	-
51	23	-	-	-	-	-	-	-	-	-	1.77	12.39	54.86	25.66	5.31
52	24	-	-	-	-	-	-	0.4	0.4	12.8	40.4	24.4	18.8	2.8	-
53	25	-	-	-	-	-	-	-	-	5.2	39.2	32.0	21.6	1.6	0.4
54	57'	-	-	-	-	-	-	-	-	4	33	36	25	2	-
55	29'	-	-	-	-	-	-	4.0	4.0	5.0	41.0	29.0	16.0	1.0	-

Appendix-II Roundness characteristics of Detrital Grains in Lower Vindhyan Sandstone of Bhadesar-Nimbahera area, Rajasthan

S. No.	Sample No.	Very Angular p	n	pxn	Angular p	n	pxn	Subangular p	n	pxn	Subrounded p	n	pxn	Rounded p	n	pxn	Well Rounded p	n	pxn	Arithmetic mean	Roundness
										KHARDEOLA SANDSTONE											
1	66	0.14	-	-	0.21	1	0.21	0.30	16	4.80	0.41	50	20.50	0.59	33	19.47	0.84	-	-	0.45	Subrounded
2	3'	0.14	-	-	0.21	-	-	0.30	22	6.60	0.41	59	24.19	0.59	19	11.21	0.84	-	-	0.42	Subrounded
3	5'	0.14	-	-	0.21	-	-	0.30	9	2.70	0.41	71	29.11	0.59	20	11.80	0.84	-	-	0.43	Subrounded
4	69	0.14	-	-	0.21	-	-	0.30	8	2.40	0.41	66	27.06	0.59	26	15.34	0.84	-	-	0.45	Subrounded
5	70	0.14	-	-	0.21	2.47	0.52	0.30	35.39	10.62	0.41	39.92	16.36	0.59	22.22	13.11	0.84	-	-	0.40	Subrounded
6	71	0.14	-	-	0.21	1.64	0.34	0.30	36.06	10.82	0.41	43.03	17.64	0.59	19.26	11.36	0.84	-	-	0.40	Subrounded
7	59'	0.14	1	0.14	0.21	9	1.89	0.30	22	6.60	0.41	58	23.78	0.59	9	5.31	0.84	-	-	0.38	Subrounded
8	45'	0.14	-	-	0.21	9	1.89	0.30	27	8.10	0.41	42	17.22	0.59	22	12.98	0.84	-	-	0.40	Subrounded
9	46'	0.14	-	-	0.21	-	-	0.30	9	2.70	0.41	56	22.96	0.59	35	20.65	0.84	-	-	0.46	Subrounded
10	62	0.14	-	-	0.21	5	1.05	0.30	19	5.70	0.41	50	20.50	0.59	26	15.34	0.84	-	-	0.42	Subrounded
11	42B'	0.14	-	-	0.21	-	-	0.30	2	0.60	0.41	45	18.45	0.59	51	30.09	0.84	2	1.68	0.51	Rounded
12	3	0.14	-	-	0.21	5.88	1.23	0.30	47.89	14.37	0.41	30.25	12.40	0.59	15.97	9.42	0.84	-	-	0.37	Subrounded
										BHAGWANPURA SANDSTONE											
13	100	0.14	-	-	0.21	-	-	0.30	12	0.60	0.41	44	18.04	0.59	36	21.24	0.84	8	6.72	0.50	Rounded
14	104	0.14	-	-	0.21	1	0.21	0.30	18	5.40	0.41	56	22.96	0.59	22	12.98	0.84	3	0.52	0.44	Subrounded
										SAWA SANDSTONE											
15	60'	0.14	-	-	0.21	2.08	0.44	0.30	22.91	6.87	0.41	54.58	22.37	0.59	19.16	11.31	0.84	1.25	1.05	0.42	Subrounded
16.	61'	0.14	-	-	0.21	2	0.42	0.30	15	4.5	0.41	60	24.6	0.59	21	12.39	0.84	2	1.68	0.44	Subrounded
17	12'	0.14	-	-	0.21	1	0.21	0.30	26	7.80	0.41	51	20.91	0.59	20	11.80	0.84	2	1.68	0.42	Subrounded
18	14'	0.14	-	-	0.21	2	0.42	0.30	19	5.70	0.41	69	28.29	0.59	10	5.90	0.84	-	-	0.40	Subrounded
19	15'	0.14	-	-	0.21	2	0.42	0.30	27	8.10	0.41	57	23.37	0.59	13	7.67	0.84	1	0.84	0.40	Subrounded
20	81	0.14	-	-	0.21	5.85	1.23	0.30	46.85	14.05	0.41	33.33	13.66	0.59	13.96	8.23	0.84	-	-	0.37	Subrounded

S. No.	Sample No.	Very Angular p	Very Angular n	Very Angular pxn	Angular p	Angular n	Angular pxn	Subangular p	Subangular n	Subangular pxn	Subrounded p	Subrounded n	Subrounded pxn	Rounded p	Rounded n	Rounded pxn	Well Rounded p	Well Rounded n	Well Rounded pxn	Arithmetic mean	Roundness
21	82	0.14	-	-	0.21	1.7	0.36	0.30	26.8	8.04	0.41	52.34	21.46	0.59	19.2	11.3	0.84	-	-	0.41	Subrounded
22	7'	0.14	-	-	0.21	-	-	0.30	8	2.40	0.41	49	20.1	0.59	43	25.37	0.84	-	-	0.48	Subrounded
23	9'	0.14	-	-	0.21	-	-	0.30	13	3.90	0.41	49	20.09	0.59	38	22.42	0.84	-	-	0.46	Subrounded
24	75	0.14	-	-	0.21	-	-	0.30	24	7.2	0.41	70	28.7	0.59	5	2.95	0.84	1	0.84	0.39	Subrounded
25	94	0.14	-	-	0.21	-	-	0.30	10	3.0	0.41	59	24.19	0.59	29	17.11	0. 84	2	1.68	0.46	Subrounded
26	95	0.14	1	0.14	0.21	12	2.52	0.30	31	9.30	0.41	42	17.22	0.59	13	7.67	0.84	1	0.84	0.37	Subrounded
27	123	0.14	-	-	0.21	-	-	0.30	24	7.20	0.41	45.33	18.59	0.59	30.7	18.10	0.84	-	-	0.44	Subrounded
28	47'	0.14	-	-	0.21	1	0.21	0.30	8	2.40	0.41	60	24.60	0.59	30	17.70	0.84	1	0.84	0.46	Subrounded
29	48'	0.14	-	-	0.21	-	-	0.30	23	6.90	0.41	39	15.99	0.59	34	20.10	0.84	4	3.36	0.46	Subrounded
30	59	0.14	-	-	0.21	-	-	0.30	4	1.20	0.41	65	26.65	0.59	28	16.52	0.84	3	2.52	0.47	Subrounded
31	8	0.14	1	0.14	0.21	3	0.63	0.30	10	3.00	0.41	58	23.78	0.59	27	15.93	0.84	1	0.84	0.44	Subrounded
32	13	0.14	-	-	0.21	6.38	1.34	0.30	37	11.11	0.41	42.6	17.44	0.59	14	8.28	0.84	-	-	0.38	Subrounded
33	14	0.14	-	-	0.21	0.39	0.08	0.30	24.4	7.32	0.41	52.4	21.47	0.59	22.4	13.24	0.84	0.4	0.33	0.42	Subrounded
KHORI - MALAN SANDSTONE																					
34	4	0.14	-	-	0.21	2	0.42	0.30	20	6.0	0.41	63	25.83	0.59	13	8.26	0.84	1	0.84	0.41	Subrounded
35	32'	0.14	-	-	0.21	2.5	0.52	0.30	30	9.0	0.41	52.5	21.52	0.59	15	8.85	0.84	-	-	0.40	Subrounded
36	33'	0.14	-	-	0.21	0.4	0.08	0.30	25.9	7.76	0.41	51.4	21.06	0.59	22.3	13.19	0.84	-	-	0.42	Subrounded
37	34'	0.14	-	-	0.21	2.5	0.52	0.30	41.7	12.52	0.41	51.6	21.17	0.59	4.13	2.48	0.84	-	-	0.36	Subrounded
38	39	0.14	1	0.14	0.21	-	-	0.30	5	1.50	0.41	57	23.37	0.59	34	20.06	0.84	3	2.52	0.47	Subrounded
39	45	0.14	1	0.14	0.21	3	0.63	0.30	20	6.00	0.41	62	25.42	0.59	14	8.26	0.84	-	-	0.40	Subrounded
40	40	0.14	-	-	0.21	1	0.21	0.30	18	5.4	0.41	54	22.14	0.59	27	15.93	0.84	-	-	0.43	Subrounded

S. No.	Sample No.	Very Angular p	n	pxn	Angular p	n	pxn	Subangular p	n	pxn	Subrounded p	n	pxn	Rounded p	n	pxn	Well Rounded p	n	pxn	Arith-metic mean	Roundness
41	53A'	0.14	-	-	0.21	3.3	0.69	0.30	35.6	10.67	0.41	56.7	23.23	0.59	0.4	2.62	0.84	-	-	0.37	Subrounded
42	49	0.14	0.4	0.05	0.21	4.4	0.92	0.30	29.2	8.76	0.41	41.2	16.89	0.59	23.2	13.69	0.84	1.6	1.34	0.41	Subrounded
43	52	0.14	-	-	0.21	17.8	3.74	0.30	43.3	12.99	0.41	34.8	14.27	0.59	4.1	2.38	0.84	-	-	0.33	Subangular
44	46A	0.14	1	0.14	0.21	5	1.05	0.30	30	9.0	0.41	54	22.14	0.59	10	5.90	0.84	-	-	0.38	Subrounded
											JIRAN SANDSTONE										
45	9B	0.14 •	-	-	0.21	0.7	0.14	0.30	19.3	5.8	0.41	56.7	23.23	0.59	23.3	13.76	0.84	-	-	0.43	Subrounded
46	10	0.14	-	-	0.21	-	-	0.30	14	4.20	0.41	68	27.88	0.59	18	10.62	0.84	-	-	0.43	Subrounded
47	11	0.14	-	-	0.21	-	-	0.30	14	4.20	0.41	67	27.47	0.59	18	10.62	0.84	1	0.84	0.43	Subrounded
48	25'	0.14	1	0.14	0.21	2	0.42	0.30	20	6.00	0.41	60	24.60	0.59	17	10.03	0.84	-	-	0.41	Subrounded
49	27'	0.14	1	0.14	0.21	5	1.05	0.30	29	8.7	0.41	56	22.96	0.59	9	5.31	0.84	-	-	0.38	Subrounded
50	26'	0.14	-	-	0.21	1	0.21	0.30	18	5.40	0.41	58	23.78	0.59	22	12.98	0.84	1	0.84	0.43	Subrounded
51	23	0.14	0.5	0.06	0.21	8.4	1.76	0.30	41.2	12.34	0.41	37.6	15.42	0.59	12.4	7.31	0.84	-	-	0.37	Subrounded
52	24	0.14	1.2	0.17	0.21	5.2	1.10	0.30	32.4	9.72	0.41	46.8	19.19	0.59	14.4	8.50	0.84	-	-	0.38	Subrounded
53	25	0.14	0.8	0.11	0.21	12.4	2.60	0.30	36.8	11.04	0.41	40	16.40	0.59	10	5.90	0.84	-	-	0.36	Subrounded
54	57	0.14	-	-	0.21	2	0.42	0.30	7	2.10	0.41	77	31.57	0.59	14	8.26	0.84	-	-	0.42	Subrounded
.55	29'	0.14	-	-	0.21	-	-	0.30	8	2.40	0.41	62	25.42	0.59	30	17.70	0.84	-	-	0.45	Subrounded

Appendix - III Mineral Composition by volume (in percent) of Lower Vindhyan Sandstone of Bhadesar - Nimbahera area, Southeastern Rajasthan.

S.No.	Sample No.	QUARTZ: Common quartz (CQ)	QUARTZ: Recrystallized Metamorphic (RMQ)	QUARTZ: Stretched Metamorphic quartz (SMQ)	QUARTZ: Reworked Sedimentary quartz (RSQ)	QUARTZ: Vein quartz (VQ)	QUARTZ: Volcanic quartz	FELDSPAR (detrital): Ortho-clase	FELDSPAR (detrital): Micro-cline	FELDSPAR (detrital): Plagio-clase	FELDSPAR (weathered): Ortho-clase	FELDSPAR (weathered): Micro-cline	Chert	Heavy minerals	Rock fragment	Mica	CEMENT: Silica	CEMENT: Iron oxide	CEMENT: Clay or Matrix
								KHARDEOLA SANDSTONE											
1	66	66.04	-	-	0.94	-	-	8.49	-	-	-	-	-	-	-	-	22.64	-	1.88
2	3'	47.48	4.31	-	3.6	-	-	-	-	-	6.47	-	3.60	7.19	-	-	7.19	-	20.14
3	5'	68.93	-	-	-	-	-	3.88	-	-	3.88	-	10.68	-	-	-	12.62	-	-
4	69	81.65	-	3.67	-	-	-	-	-	-	-	-	-	-	-	-	14.68	-	-
5	70	50.25	11.44	4.97	28.85	0.99	0.50	0.50	-	-	0.99	-	-	-	-	-	1.49	-	-
6	71	30.45	30.0	5.0	28.63	-	0.91	-	-	-	-	-	-	-	0.91	-	4.10	-	-
7	59'	40.0	6.0	4.0	3.0	30.0	-	1.0	-	-	-	-	2.0	-	-	-	11.0	3.0	-
8	45'	67.32	3.96	-	2.97	-	-	-	-	-	-	-	-	-	-	-	25.74	-	-
9	62	67.31	-	-	-	-	-	-	-	-	-	-	-	-	-	2.88	-	-	29.81
10	42'B	38.0	5.0	5.0	27.0	-	-	-	-	-	4.0	2.0	5.0	-	-	-	13.0	-	1.00
11	3	50.69	8.29	-	17.97	-	-	1.84	2.30	0.46	-	-	-	0.46	9.22	0.46	7.83	-	0.46
								BHAGWANPURA SANDSTONE											
12	100	47.46	-	-	23.73	-	-	-	-	-	3.39	-	0.85	-	-	-	20.34	-	4.24
13	104	54.41	12.5	-	-	-	-	-	-	-	1.47	-	3.68	-	-	-	15.44	-	12.5
								SAWA SANDSTONE											
14	60'	3.75	1.25	0.83	70.83	-	-	-	-	-	8.33	-	1.66	-	-	-	10.42	0.83	2.08
15	61'	11.48	-	5.26	65.55	-	-	2.39	-	2.87	9.09	-	-	-	-	-	3.35	-	-
16	12'	70.94	6.84	0.85	8.55	-	-	-	-	-	-	-	-	-	-	-	8.54	-	4.27
17	14'	47.0	6.0	12.0	8.0	-	-	7.0	4.0	-	-	-	-	-	4.0	-	7.0	-	5.0
18	15'	38.74	6.31	-	-	-	-	-	2.70	-	7.21	7.21	-	3.60	-	-	-	-	34.23
19	81	7.96	27.86	10.94	22.39	3.98	6.47	3.98	-	-	13.93	-	-	-	2.49	-	-	-	-
20	82	4.36	6.55	-	69.87	2.62	3.05	4.80	-	-	-	-	-	-	-	-	8.73	-	-
21	7'	63.11	11.65	13.59	0.97	-	-	-	-	-	-	-	1.94	-	-	-	8.74	-	-
22	94	56.60	1.89	13.21	4.72	-	-	12.26	-	-	0.94	-	-	-	-	-	-	-	10.38
23	95	59.80	1.96	4.90	-	-	-	3.92	-	-	20.59	-	-	-	-	-	-	-	8.82
24	123	60.87	0.87	5.22	-	4.35	-	5.22	2.61	-	8.70	-	-	-	-	-	12.17	-	-

S.No.	Sample No.	QUARTZ: Common quartz (CQ)	Recrystallized Metamorphic (RMQ)	Stretched Metamorphic quartz (SMQ)	Reworked Sedimentary quartz (RSQ)	Vein quartz (VQ)	Volcanic quartz	FELDSPAR (detrital): Ortho-clase	Micro-cline	Plagio-clase	FELDSPAR (weathered): Ortho-clase	Micro-cline	Chert	Heavy minerals	Rock fragment	Mica	CEMENT: Silica	Iron oxide	Clay or Matrix
25	47'	80.55	1.85	-	-	-	-	-	-	-	1.85	-	-	-	-	-	14.81	-	0.92
26	48'	65.81	2.56	-	8.55	-	-	-	-	-	5.85	-	1.71	-	-	-	15.38	-	-
27	8	44.0	-	4.0	-	41.0	-	-	-	-	4.0	-	-	-	-	-	7.0	-	-
28	13	28.57	2.30	-	47.46	-	13.82	-	-	-	-	-	2.76	-	1.38	-	3.69	-	-
29	14	27.87	8.61	4.10	47.95	-	3.69	-	-	-	-	-	7.79	-	-	-	-	-	-
								KHORI-MALAN SANDSTONE											
30	4	71.70	2.83	-	2.83	4.72	-	0.94	-	-	-	-	-	-	-	-	16.98	-	-
31	32'	1.07	-	8.02	71.66	-	-	-	-	-	-	-	-	1.60	-	-	17.65	-	-
32	33'	6.11	6.11	33.19	41.48	4.80	-	-	-	-	-	-	7.86	0.44	-	-	-	-	-
33	34'	9.52	-	-	67.46	0.79	-	-	-	-	-	-	5.16	1.19	-	-	0.79	8.33	6.75
34	39	70.27	-	4.50	1.80	-	-	-	-	-	-	-	10.81	-	-	-	12.61	-	-
35	45	62.26	13.21	-	-	-	-	-	-	-	-	-	-	-	-	-	2.83	11.32	10.38
36	53'A	47.46	-	28.81	-	3.39	-	-	-	-	-	-	6.80	-	-	-	-	-	13.56
37	49	69.81	3.77	-	4.72	2.83	-	-	-	-	-	-	0.94	-	-	-	17.92	-	-
38	52	40.36	8.97	4.93	13.45	1.79	6.28	-	-	-	-	-	2.24	0.89	2.24	2.24	0.89	-	15.69
								JIRAN SANDSTONE											
39	98	44.81	7.79	-	6.49	7.79	-	-	-	-	-	-	11.69	0.65	-	-	13.64	7.14	-
40	10	1.0	25.0	4.0	-	48.0	-	-	-	-	-	-	-	-	-		22.0	-	-
41	25'	60.38	-	-	-	9.43	-	-	-	-	-	-	-	0.94	-	-	26.42	2.83	-
42	27'	73.68	-	-	-	1.75	-	-	-	-	-	-	-	0.88	-	-	2.63	21.05	-
43	26'	58.33	-	-	10.19	0.93	-	-	-	-	3.70	-	-	-	2.77	0.93	21.30	-	1.85
44	23	76.11	-	-	-	-	-	-	-	-	-	-	-	-	2.21	1.3	7.68	3.73	8.95
45	24	52.46	-	31.15	-	-	-	-	-	-	-	-	-	-	-	-	16.39	-	-
46	25	88.0	8.80	2.0	-	-	-	0.40	-	-	-	-	0.40	0.40	-	-	-	-	-
47	57	62.68	-	-	-	22.39	-	-	-	-	-	-	-	-	-	-	13.43	-	1.49
48	29'	58.0	1.0	-	-	3.0	-	-	-	-	-	-	-	2.0	-	-	18.0	-	8.0

Appendix - IV Recalculated by Number Percentage of essential constituents used in classification of Lower Vindhyan Sandstones after Folk (1980).

S. No.	Sample Number	Q	F	RF
		KHARDEOLA SANDSTONE		
1	66	88.75	11.25	-
2	3'	84.62	9.88	5.5
3	5'	78.9	8.9	12.22
4	69	100.0	-	-
5	70	98.49	1.51	-
6	71	99.05	-	0.95
7	59'	96.51	1.16	2.33
8	45'	100.0	-	-
9	62	100.0	-	-
10	42'B	87.21	6.97	5.81
11	3	84.77	5.06	10.16
		BHAGWANPURA SANDSTONE		
12	100	94.38	4.49	1.13
13	104	92.85	2.04	5.11
		SAWA SANDSTONE		
14	60'	88.47	9.61	1.91
15	61'	85.15	14.84	-
16	12'	100.0	-	-

S. No.	Sample Number	Q	F	RF
17	14'	82.95	12.5	4.55
18	15'	72.46	27.54	-
19	81	79.6	17.91	2.49
20	82	94.74	5.26	-
21	7'	97.87	-	2.12
22	94	85.27	14.73	-
23	95	73.11	26.88	-
24	124	81.18	18.81	-
25	47'	97.80	2.19	-
26	48'	90.91	7.07	2.02
27	8	95.70	4.30	-
28	13	95.70	-	4.30
29	14	92.22	-	7.79
		KHORI-MALAN SANDSTONE		
30	4	98.86	1.13	-
31	32'	100.0	-	-
32	33'	92.10	-	7.89
33	34'	93.78	-	6.22
34	39	87.63	-	12.37
35	45	100.0	-	-
36	53'A	92.14	-	7.86
37	49	98.85	-	1.15
38	52	94.42	-	5.58

S. No.	Sample Number	Q	F	RF
		JIRAN SANDSTONE		
39	9B	85.12	-	14.88
40	10	100.0	-	-
41	25'	100.0	-	-
42	27'	100.0	-	-
43	26'	91.48	4.87	3.65
44	23	100.0	-	-
45	24	100.0	-	-
46	25	99.20	0.40	0.40
47	57	100.0	-	-
48	29'	100.0	-	-

Appedix - V   Recalculated by Number Percentage of Detrital Constituents used in Classification of Lower Vindhyan Sandstone according to Dickinson (1985).

S. No.	Sample Number	Qt	F	L	Qm	F	Lt	Qp	Lv	Ls	Qm	P	K
					KHARDEOLA SANDSTONE								
1	66	88.60	11.39	-	88.60	11.39	-	-	-	-	88.60	-	11.39
2	3'	89.54	10.45	-	82.50	11.24	6.25	100	-	-	88.0	-	12.0
3	5'	91.11	8.88	-	78.89	8.89	12.22	100	-	-	89.88	-	10.11
4	69	100	-	-	95.69	-	4.30	100	-	-	100	-	-
5	70	97.86	2.13	-	74.29	2.13	23.56	100	-	-	97.20	-	2.79
6	71	98.64	-	1.35	46.61	-	53.38	97.46	-	2.53	100	-	-
7	59'	98.79	1.20	-	84.33	1.20	14.49	100	-	-	98.59	-	1.40
8	45'	100	-	-	94.44	-	5.56	100	-	-	100	-	-
9	62	100	-	-	100	-	-	-	-	-	100	-	-
10	42'B	89.83	10.16	-	64.4	10.16	25.42	100	-	-	86.36	-	13.63
11	3	81.01	6.31	12.66	69.62	6.31	24.05	47.34	-	52.65	91.68	0.83	7.48
					BHAGWANPURA SANDSTONE								
12	100	93.44	6.55	-	91.79	6.55	1.64	100	-	-	93.33	-	6.66
13	104	97.96	2.03	-	75.50	2.03	22.45	100	-	-	97.36	-	2.63
					SAWA SANDSTONE								
14	60'	47.34	52.65	-	23.70	52.65	23.64	100	-	-	31.04	-	68.95
15	61'	53.84	46.15	-	36.92	46.15	16.91	100	-	-	44.44	11.11	44.44
16	12'	100	-	-	90.22	-	9.77	100	-	-	100	-	-
17	14'	81.25	13.75	5.0	58.75	13.75	27.5	81.81	-	18.18	81.03	-	18.96

S. No	Sample Number	Qt	F	L	Qm	F	Lt	Qp	Lv	Ls	Qm	P	K
18	15'	72.46	27.53	-	48.85	21.59	29.54	100	-	-	69.35	-	30.64
19	81	73.71	23.07	3.2	23.72	23.07	53.20	93.96	-	6.03	50.68	-	49.31
20	82	77.54	22.45	-	46.91	22.45	30.63	100	-	-	67.63	-	32.36
21	7'	100	-	-	69.89	-	30.10	100	-	-	100	-	-
22	94	84.45	15.54	-	66.66	15.54	17.78	100	-	-	81.08	-	18.91
23	95	73.11	26.88	-	65.59	.26.88	7.52	100	-	-	70.92	-	29.07
24	123	81.18	18.81	-	74.24	18.81	6.93	100	-	-	79.77	-	20.22
25	47'	97.80	2.19	-	95.6	2.19	2.19	100	-	-	97.75	-	2.24
26	48'	92.13	7.86	-	86.52	7.86	5.61	100	-	-	91.67	-	8.32
27	8	95.69	4.30	-	91.39	4.30	4.30	100	-	-	95.50	-	4.49
28	13	96.24	-	3.75	85.98	-	14.01	73.22	-	26.77	100	-	-
29	14	100	-	-	60.62	-	39.37	100	-	-	100	-	-
					K H O R I - M A L A N S A N D S T O N E								
30	4	98.82	1.17	-	95.29	1.17	3.52	100	-	-	98.78	-	1.21
31	32'	100	-	-	11.77	-	88.82	100	-	-	100	-	-
32	33'	100	-	-	18.78	-	81.21	100	-	-	100	-	-
33	34'	100	-	-	66.64	-	33.35	100	-	-	100	-	-
34	39	100	-	-	82.11	-	17.88	100	-	-	100	-	-
35	45	100	-	-	82.49	-	17.50	100	-	-	100	-	-

S. No	Sample Number	Qt	F	L	Qm	F	Lt	Qp	Lv	Ls	Qm	P	K
36	53'A	100	-	-	58.81	-	41.18	100	-	-	100	-	-
37	49	100	-	-	93.91	-	6.08	100	-	-	100	-	-
38	52	96.64	-	3.35	72.48	-	27.51	87.81	-	12.18	100	-	-
						JIRAN SANDSTONE							
39	9B	100	-	-	72.97	-	27.02	100	-	-	100	-	-
40	10	100	-	-	62.82	-	37.17	100	-	-	100	-	-
41	25'	100	-	-	100	-	-	-	-	-	100	-	-
42	27'	100	-	-	100	-	-	-	-	-	100	-	-
43	26'	90.15	5.62	4.21	90.15	5.62	4.21	-	-	100	94.12	-	5.87
44	23	97.17	-	2.82	97.17	-	2.82	-	-	100	100	-	-
45	24	100	-	-	62.74	-	37.25	100	-	-	100	-	-
46	25	99.59	0.40	-	88.35	0.40	11.24	100	-	-	99.54	-	0.45
47	57	100	-	-	100	-	-	-	-	-	100	-	-
48	29'	100	-	-	98.61	-	1.38	100	-	-	100	-	-

Appendix - VI Cross-bedding foreset dip azimuth, inclination and thickness of Lower Vindhyan Sandstone in Bhadesar - Nimbahera area.

Locality Number	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)
			Trough Cross-bedding			
1	309/14		305/8	40	241/23	
	271/17		155/20		185/17	32
	201/21		276/28			
2	310/10		2/15		35/35	
	23/10		76/13		134/17	
	131/21		165/15			
3	230/37		279/20		245/30	
	221/31		206/28		205/29	
	106/13		161/30		158/12	
	180/26		171/21		160/19	
4	213/13		218/27		212/40	
	227/20		203/35		207/59	
	130/31		142/26		157/27	
	165/28		174/31		192/41	
5	170/39		39/19		63/9	9
	92/10	8	45/16		78/12	
	112/12		165/26			
6	336/6		192/16		100/8	
	102/16	16	80/15		88/18	
	105/14		109/12		185/17	
	340/8					
7	68/8		95/13		81/5	6
	143/14		151/20		71/9	
	92/14		87/7		126/12	
	168/16					
8	335/16		321/10		345/20	
	355/12		328/15		275/10	
	95/18		112/20		94/23	
	118/21		110/24		143/17	

Locality Number	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)
9	95/10		103/7		71/7	
	308/20		97/16		318/26	
	325/23		302/21			
10	55/10		28/10		64/36	
	56/25		58/15		75/10	
	12/24		109/22		312/19	
	308/16		323/26		341/28	
11	99/17		92/12		113/8	
	124/18		128/20		108/15	
	121/9		113/21			
12	346/40		337/12		195/60	
	100/18		150/20		15/27	
	70/28		155/12		217/18	
	242/15					
13	175/28		147/20		195/15	
	165/25		128/22		156/19	
	171/21		201/17			
14	215/20		175/20		200/40	
	222/15		162/16		207/24	
	218/19		227/21			
15	165/25		190/20		250/15	
	171/19		197/22		248/17	
16	140/15		150/15		160/20	
	165/20		191/10		123/12	
	137/14		154/18			
17	29/21	15	60/6		36/10	
	285/26		310/23		326/20	
18	147/16		131/9		128/15	
	53/50		21/17		43/25	
	51/28		119/23			
19	44/48		32/7		40/37	
	25/7		108/19		137/23	
	185/17		196/35			

Locality Number	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)
20	43/45		56/20		76/25	
	82/33		131/22		143/19	
	175/24		154/17			
21	35/15		188/5		190/9	
	125/19		332/19		346/16	
22	174/18		154/15		149/17	
	158/17		165/18		159/18	
	37/19		20/12		28/14	
	145/15		166/12		200/15	
	147/10		178/14		165/11	
	131/13		152/15		159/10	
	154/17		46/18		19/13	
	25/14		139/16		171/13	
	189/12		136/9			
23	152/12		210/12		188/12	
	171/12		192/12		204/10	
	111/12		166/12		185/10	
	100/12		93/10		55/10	
	205/10		193/10		159/11	
	205/10		184/12		165/13	
	198/10		208/12		115/11	
	154/9		182/10		108/14	
	112/10		46/9		187/11	
	197/10					
24	24/10		5/10		95/10	
	21/9		27/11		98/10	
25	158/25		153/23		174/20	
	143/20		46/20		148/17	
	161/19		168/21		172/22	
	138/19		41/20		139/20	
26	160/17		164/15		170/17	
	168/15		174/20		112/20	
	157/16		176/17		171/18	
	161/16		173/19		108/20	

Locality Number	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)
27	240/5		210/14		178/13	
	190/8		234/6		186/8	
	205/12		165/11			
28	280/18		285/13		355/23	
	340/15		276/18		291/16	
	346/19		342/20			
29	3/17		278/15		355/10	
	8/7		5/9		283/18	
	351/11		16/8			
30	347/10		356/12		336/12	
	352/10		345/11		339/12	
	349/10		335/9			
31	53/35		44/12	20	208/20	30
	190/7		12/26		134/30	
	167/34		348/37			
32	185/30		175/8		215/25	
	217/8		43/38		37/34	
	55/39		39/32			
33	56/11		45/14	17	20/25	11
	57/14		30/17		48/12	
	53/11		34/10		25/15	
34	205/20		210/15		290/14	
	40/15		150/15		182/17	
	185/17		210/15		195/17	
	190/18		194/17		203/14	
	189/15		198/16		207/13	
	49/14		141/15		287/17	
35	54/15		38/17		5/17	
	355/17		240/12		215/12	
	188/12		234/10		168/10	
	166/10		46/13		331/16	
	344/15		111/17		223/12	
	228/11		218/12		194/14	
	157/10		172/13			

Locality Number	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)
36	132/10		165/10		140/5	
	142/10		136/9		147/8	
	144/9		158/10			
37	162/15		80/60		141/15	
	78/21		82/22		95/17	
	133/16		155/15			
38	55/20		198/11		212/15	
	62/15		51/18		205/12	
	219/14		77/15			
39	34/21		40/10		174/6	
	218/15		210/18	5	193/25	
	258/11		45/18		38/16	
	167/8		207/23		198/21	
	226/15		247/13			
40	165/9		213/11		211/10	
	58/15		230/10	7	13/14	
	190/17		172/10		218/12	
	225/9		231/13		43/14	
	19/13		187/16			
41	125/16	8	165/10		132/14	
	174/11					
42	101/19		303/13		340/25	
	302/5		35/16		48/18	
	115/17		98/19		93/17	
43	190/4	30	315/21		17/22	
	47/13		23/21		14/19	
	198/6		187/5		38/13	
44	228/10	10	204/24		205/35	
	210/31		207/30		235/9	
45	125/10		75/10		31/12	
	170/15		92/10		100/10	
	134/9		64/10		46/11	
	161/10		97/13		106/12	

Locality Number	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)
46	320/15		172/15		355/10	
	301/10		170/10		130/10	
	140/15		285/10		295/15	
	305/11		198/15		341/11	
	309/10		162/12		126/10	
	144/10		278/11		288/12	
47	41/9		98/10		110/11	
	124/10		133/9		158/13	
	164/12		52/10		92/11	
	105/12		138/10		122/10	
	170/12		152/13			
48	335/20		340/34		355/20	
	285/23		225/20		332/21	
	344/22		350/21		291/22	
	230/19					
49	215/15		325/15		310/28	
	326/17		226/14		312/16	
	318/29		322/20			
50	240/15		270/20		260/15	
	230/17		228/20		292/20	
	221/18		261/19		254/20	
	225/17		232/16		278/20	
51	297/21	9	255/19		261/22	
	300/35		273/20		320/48	20
	285/20		248/20		264/19	
	296/31		275/19		311/25	
52	263/42		310/22	18	35/20	
	310/6	18	315/10		257/35	
	315/21		40/19		320/10	
	306/12					
53	10/17		25/13		20/13	
	72/20		16/12		11/14	
	23/11		68/19			

Locality Number	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)
54	12/24		80/20		40/17	
	60/15		16/22		86/18	
	45/16		53/14			
55	63/17		43/20		80/12	
	78/12		25/18		65/16	
	36/19		84/13		72/11	
	16/15					
56	35/12		12/17		55/17	
	17/12		34/10		46/14	
	16/13		34/16		23/11	
	42/11					
57	42/10		53/20		35/17	
	70/18		45/10		55/18	
	48/12		75/14			
58	340/18	12	311/26	10	325/23	
	298/28		295/27		316/21	
	308/26	20	347/17		315/20	
	318/21		285/22		290/19	
	320/20		314/24			
59	314/20		5/22		267/12	
	329/20		333/7		344/17	
	307/15		288/16		308/19	
	12/20		256/11		324/21	
	338/10		347/15		319/14	
	298/13					
60	258/4		286/13		317/16	
	303/33		248/20		300/15	
	266/20		335/12		246/7	
	274/12		321/14		310/25	
	253/18		294/15		252/19	
	343/14					
61	359/15		22/17		5/20	
	335/7		325/5		358/17	
	350/13		341/14		17/13	

Locality Number	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)
	11/17		337/8		312/7	
	341/15		332/12			
62	15/7		21/6		25/22	
	20/5		10/20		250/32	
	305/20		6/9		18/7	
	21/6		9/13		15/10	
	242/24		310/16			
63	5/3		331/10		355/15	
	329/17		350/15		358/9	
	13/4		335/12		350/14	
	318/16		338/11		347/10	
64	332/23		260/9		329/5	
	274/10		355/15		305/12	
	342/21		248/10		312/8	
	282/11		351/14		324/12	
65	220/23		282/27		288/24	
	262/18		253/10		235/16	
	290/6		297/7		287/7	
	338/4		132/36		67/30	
	72/31		98/35		106/32	
	114/34		98/36		74/33	
	97/28		83/39			
66	239/10		230/6		248/23	
	150/4		355/19		333/23	
	194/7		223/6		224/19	
	188/8		306/31		335/34	
	339/36		308/32		346/21	
	343/38					
67	261/9		299/10		280/12	
	301/13		279/6		171/30	
	191/32		241/14		244/10	
	237/13		260/16		275/10	
	201/30		205/26		198/24	
	192/25		184/23		339/30	
	321/31					

Locality Number	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)
68	328/4		315/8		320/15	20
	319/12		20/5	10	23/7	
69	29/15		79/5		50/15	
	10/12		104/8		81/15	
	95/7		97/10		84/14	
	115/10		23/14		61/6	
	39/15		18/11			
70	42/10		8/5		47/10	
	5/7		27/10		35/7	
	10/5		35/8		15/6	
	40/9		21/7		24/9	
	42/8		18/6			
71	299/15		310/17		296/5	
	225/25		260/15		275/6	
	321/14		231/20		284/18	
	265/17					
72	204/5		315/11		308/14	
	187/7					
73	10/25		15/22	8	14/15	
	6/30		73/28		78/27	
	82/26		46/24			
74	7/13		329/30		310/27	17
	345/15	20	315/8		352/7	
	347/3		12/13		318/29	
	318/26		355/16		305/9	
	348/10		341/4			
75	205/25		206/24		3/7	
	339/21		130/8		33/14	7
	3/22	17	122/12		135/16	
	285/18		159/17		125/9	
	42/12		285/15		16/21	
	138/14					
76	17/11		340/7		2/6	
	40/15		12/3	6	348/6	

Locality Number	Foreset azimuth/ inclination (in degree)	Thick- ness (cm)	Foreset azimuth/ inclination (in degree)	Thick- ness (cm)	Foreset azimuth/ inclination (in degree)	Thick- ness (cm)
	15/5		10/8		46/10	
	21/5					
77	350/15		12/8		3/2	
	73/6	11	345/14		18/7	
	20/5		68/5			
78	157/21		138/7		15/16	
	100/18	5	112/12		143/14	
	152/18		195/23		161/13	
	125/8		22/15		115/16	
	108/11		136/13		165/18	
	202/21					
79	207/15		62/24		129/14	
	140/17		140/7		147/6	
	135/33		137/5		280/26	
	208/54		146/14		215/12	
	68/23		136/12		126/17	
	141/8		148/9		134/40	
	137/5		291/23		185/29	
	132/14					
80	144/13		178/35		170/4	
	101/6		280/18		195/6	
	192/25		130/28		135/16	
	131/15		158/22		163/7	
	115/7		287/15		205/7	
	187/20		142/20		145/17	
81	177/25	17	205/32	20	167/15	
	188/23		230/30		278/18	
	217/12		212/16		303/10	
	230/29		287/17		245/29	
	315/25		290/17		280/12	
	165/15		312/23		284/27	
	160/12		294/18			
82	210/18	16	315/34		345/10	
	308/12		16/32		35/20	

Locality Number	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)
	18/23		23/18		320/22	
	156/24		172/12		155/25	
	110/26		135/21		140/13	
	126/14					
83	295/5		302/19		272/12	
	222/13		236/16		190/22	
	215/21		187/24		345/20	
	315/19					
84	5/14		16/34		340/13	
	75/22		23/11		44/18	
	95/15		27/10		15/12	
	337/5		340/20		328/7	
	278/21		10/15		19/20	
	332/14		63/21		29/12	
	50/16		110/13		23/12	
	9/13		345/9		348/16	
	314/9		289/20			
85	38/5		36/9		57/15	
	125/22		135/21		110/19	
86	70/10		75/15		29/10	
	31/10		45/15		43/20	
	19/11		65/14		21/9	
	37/11		55/13		44/15	
87	355/15		20/25		335/25	
	350/20		356/20		328/15	
	343/14		16/23		354/18	
	334/19		317/14		344/21	
88	310/20		335/20		75/20	
	305/20		310/20		285/15	
	15/20		317/19		347/21	
	69/18		319/16		325/17	
	279/15		23/18			
89	58/23	18	52/3	50	43/11	10
	15/17	16	25/12	20	55/18	

Locality Number	Foreset azimuth/ inclination (in degree)	Thick- ness (cm)	Foreset azimuth/ inclination (in degree)	Thick- ness (cm)	Foreset azimuth/ inclination (in degree)	Thick- ness (cm)
	30/11		36/12		44/14	
	33/10		22/14		18/11	
	39/17		28/10			
90	20/5		2/15		344/19	12
	338/16	13	45/10		155/24	
	164/21		180/16		177/18	
	157/19					
91	330/11		351/15		20/19	10
	23/13	16	15/5	40	171/21	
	168/20		126/23		132/19	
	165/20					
92	321/10		26/9		55/15	
	20/15	14	174/23		156/24	
	132/25		145/20			
93	220/30		272/20		274/14	
	265/7		266/25		288/17	
	239/15		216/26		281/21	
	287/13		258/8		264/21	
	274/18		225/14			
94	285/22		38/36		285/35	
	278/39		261/20		249/20	
	292/23		42/24		296/31	
	272/30		245/19		252/21	
95	75/17		67/26		338/5	
	42/20		80/18		72/19	
	342/8		36/21			
96	22/27		175/7		150/12	
	190/13		16/23		163/8	
	157/11		184/12			
97	310/20		290/10		105/10	
	25/10		150/10		130/5	
	321/18		282/11		94/12	
	13/9		146/7		123/10	
98	65/6		345/5		328/5	

Locality Number	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)
	15/5		130/5		118/5	
	73/7		353/8		315/6	
	23/7		137/5		108/5	
99	45/6		50/6		80/10	
	146/5		70/10		40/6	
	194/17		188/19		162/30	
	23/24		164/21		193/21	
100	35/7		8/14		102/3	
	325/10		320/8		307/8	
	205/15		194/19		185/24	
	202/21		111/20		98/19	

Planar Cross-bedding

A	153/8		169/11		177/10	
	162/6		147/9			
B	140/12		188/7		181/14	
	145/18		138/17			
C	62/30		60/29		102/12	
	88/8		97/12		81/7	
	93/21		99/24			
D	119/6		125/17		131/11	
	145/5		138/10		133/16	
E	95/13		151/20		100/18	8
	91/15		160/19	7	108/16	
F	165/10		118/17		88/9	
	94/13		170/21		178/10	
G	146/8		123/7		165/10	10
	172/12		142/8		135/9	
	155/12		165/8		152/14	
	179/8					
H	228/10		217/12		219/12	
	235/16		204/22		206/26	8
	186/15		192/16		197/21	
	208/18					

Locality Number	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)
I	268/12		210/18		258/11	
	230/10		214/16		225/17	6
	221/14		165/8		172/7	
	188/21		202/16			
J	220/11		216/12		218/15	
	265/12		249/10		223/9	
	191/15		199/14		156/9	
	162/7					
K	17/22		25/15		29/16	
	18/11		35/12		41/10	
	65/8		351/13			
L	20/25		36/16		30/17	
	41/14		10/23		21/13	
	16/12					
M	25/18		24/15		40/20	4
	43/19		346/14		16/12	
	14/18		36/17			
N	205/20		178/17		201/18	
	168/14		189/16		213/15	
	190/15		161/11			
O	309/25		306/22		315/20	
	320/17		336/19		339/16	10
	13/9		38/17		297/26	
P	320/48		310/28		335/24	
	294/21	15	315/29		5/19	
Q	263/42		248/35		254/32	
	282/36		205/31		258/27	
R	320/15		310/12		337/11	
	305/16		345/8	10	101/13	
	292/8					
S	308/4		325/6		317/12	
	333/12		285/11		305/8	
	24/10		12/9			

Locality Number	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)	Foreset azimuth/ inclination (in degree)	Thick-ness (cm)
T	40/50		12/3		32/55	
	22/8		346/13		62/22	6
	48/21		70/18			
U	73/6		85/9		49/7	
	27/4		68/6		98/11	10
	55/4		77/16		111/5	

Appendix - VII Tilt correction of Foreset dip azimuth according to Potter & Pettijohn (1977, P. 371).

Locality Number	Bedding Strike (degree)	Bedding Dip (degree)	Cross-bed Strike (degree)	Cross-bed Dip (degree)	Tilt corrected Strike (degree)	Tilt corrected Dip (degree)	Thickness (cm)
			Trough Cross-bedding				
1	164	30E	309	14SW	193	24SE	
			305	8SW	175	24E	40
			241	23NW	298	32NE	
			271	17N	198	30W	
3	279	31SW	230	37SE	179	28E	
			279	20S	99	11N	
			245	30SE	174	17E	
			221	31NW	165	29W	
			206	28SE	152	34E	
			205	29SE	153	34E	
2	279	31SW	310	10SW	178	22E	
			2	15W	146	15NE	
			35	35SE	85	30S	
			23	10SE	146	23SW	
4	279	31SW	207	59NW	185	55NW	
			213	13SE	125	28NE	
			218	27SE	154	29NE	
			212	40SE	172	38NE	
			227	20SE	138	24NE	
			203	35SE	160	40NE	
8	302	38NE	335	16NE	103	26SW	
			321	10NE	116	28SW	
			345	20E	91	26SE	
			355	12E	105	32SW	
			328	15E	106	24SW	
			275	10N	131	29SW	
9	302	38E	95	10NE	312	29SW	
			103	7SW	306	31NE	
			71	7SE	315	35NE	
			308	20NE	113	18SW	

Locality Number	Bedding Strike (degree)	Bedding Dip (degree)	Cross-bed Strike (degree)	Cross-bed Dip (degree)	Tilt corrected Strike (degree)	Tilt corrected Dip (degree)	Thickness (cm)
10	302	38E	55	10SE	318	35NE	
			64	36SE	5	34E	
			56	25SE	345	35E	
			28	10SE	106	38SW	
			58	15NW	327	35SW	
			75	10NW	317	32SW	
12	93	27S	346	40W	20	40W	
			337	12SW	63	24NW	
			195	60E	179	58E	
			100	18N	260	9S	
			150	20SW	224	23NW	
17	288	30N	29	21NW	329	33SW	15
			60	6SE	297	26NE	
			36	10NW	309	29SW	
18	15	48NE	147	16SW	35	39NW	
			131	9NE	27	43SE	
			128	15NE	35	44NW	
			53	50SE	112	28SW	
19	15	48NE	44	48NW	115	21NE	
			32	7SE	192	41NW	
			40	37SE	148	20SW	
			25	7SE	193	41NW	
20	15	48NE	43	45SE	124	20SW	
			56	20NW	171	35NE	
			76	25SE	160	41SW	
			82	33SE	149	44SW	
21	356	26W	35	15E	141	17W	
			188	5W	352	21E	
			190	9W	349	17E	
31	185	58E	53	35SE	143	40SW	
			44	12SE	175	48W	20
			208	20SE	354	40W	30
			190	7E	4	51W	
32	215	65E	185	30E	58	41NW	
			175	8E	41	58NW	

Locality Number	Bedding Strike (degree)	Bedding Dip (degree)	Cross-bed Strike (degree)	Cross-bed Dip (degree)	Tilt corrected Strike (degree)	Tilt corrected Dip (degree)	Thickness (cm)
			215	25E	35	40NW	
			217	8E	34	57NW	
42	287	25SW	303	13SW	93	13NE	
			302	5SW	102	20NE	
			340	25SW	42	21NW	
43	287	25SW	315	21S	50	11NW	
65	94	54N	220	23NW	121	43SW	
			282	27NW	88	28S	
			288	24NW	85	31S	
			262	18NW	102	36S	
			253	10NW	100	46S	
			235	16NW	110	42S	
			290	6NW	92	48S	
			297	7NW	90	48S	
			287	7NW	92	47S	
			338	4NE	89	51S	
66	346	47W	239	10NW	332	45NE	
			230	6NW	338	44NE	
			248	23SE	314	48SW	
			194	7W	341	41NE	
			223	6NW	339	44NE	
			224	19SE	320	40SW	
			150	4W	348	43NE	
			188	8W	341	40NE	
67	350	41W	261	9S	184	42SE	
			299	10SW	185	35SE	
			280	12SW	189	39SE	
			301	13SW	189	33SE	
			241	14NW	328	38E	
			244	10NW	334	39E	
			237	13NW	330	36E	
			260	16S	194	44SE	
			279	6S	180	39E	
			275	10S	187	39E	

Locality Number	Bedding Strike (degree)	Bedding Dip (degree)	Cross-bed Strike degree)	Cross-bed Dip (degree)	Tilt corrected Srtike (degree)	Tilt corrected Dip (degree)	Thickness (cm)
73	300	29NE	10	25E	69	30SE	
			15	22E	75	31SE	8
			14	15E	88	28S	
			6	30E	59	31SE	
75	340	26SW	205	25E	272	19S	
			3	7W	151	19NE	
			339	21W	160	5E	
			206	24NW	276	19N	
81	325	35NE	177	25W	281	18N	17
			205	32NW	265	32N	20
			167	15SW	310	24NE	
			188	23SE	284	24SW	
			230	30NW	278	42N	
			278	18N	178	25W	
			217	12NW	303	33NE	
			212	16SE	297	32S	
			303	10SW	154	25NE	
			230	29NW	279	42N	
82	325	57E	210	18NW	315	48NE	16
			315	34SW	178	26E	
			345	10W	151	47NE	
			308	12SW	162	46NE	
			16	32E	120	36SW	
			35	20E	130	48SW	
			18	23E	131	42SW	
			23	18E	137	46SW	
83	357	31W	295	5SW	186	29E	
			302	19W	217	25SE	
			272	12S	201	32SE	
			222	13NW	331	23NE	
			236	16NW	323	26NE	
85	325	30E	38	5SE	136	28SW	
			36	9SE	125	28SW	
			57	15SE	116	33SW	

Locality Number	Bedding Strike (degree)	Bedding Dip (degree)	Cross-bed Strike (degree)	Cross-bed Dip (degree)	Tilt corrected Strike (degree)	Tilt corrected Dip (degree)	Thickness (cm)
90	347	43E	20	5E	162	39W	
			2	15E	160	29W	
			344	19SW	171	23NE	12
			338	16SW	174	27NE	13
			45	10NE	151	38SW	
91	340	41E	330	11SW	164	31NE	
			351	5SW	158	36NE	
			20	19E	136	29SW	10
			23	13E	145	32SW	16
			15	5E	155	37W	40
92	342	40E	321	10SW	171	31E	
			26	9E	152	34SW	
			55	15SE	138	38SW	
			20	15E	143	30SW	14
99	10	55E	45	6E	185	50W	
			50	6E	185	50W	
			80	10S	178	52W	
			146	5NE	14	51W	
			70	10S	179	50W	
			40	6E	187	50W	
100	10	50E	35	7NW	186	43E	
			8	14NW	191	36E	
			102	3S	186	50W	
			325	10NE	200	43W	
			320	8NE	119	44W	
			307	8NE	120	46W	
			Planar Cross-bedding				
C	345	37W	62	30NW	116	40NE	
			60	29NW	117	39E	